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DESIGN MANUAL FOR SURFACE MINE HAULROADS

by

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LETTER OF TRANSMITTAL

TO COME

EXECUTIVE SUMMARY

TO COME

PROLOGUE

One of the first objects which occupies the attention of an energetic people, when they are striving to advance in the march of improvement, and to take a higher standing amongst the nations of the earth, is the forming and establishing of roads and other mediums of communication, in order to promote the development of the resources of their own country, and to enable them to maintain a commercial and social intercourse with foreign nations...

In selecting a line of road where two lines present nearly equal advantages and disadvantages, the cheapest road ought to be preferred, but in making the selection reference ought to be had, not only to the original cost of construction and the future repairs, but also to the relative expense of animal strength required to draw carriages upon each line... Roads ought to be carried along a level line as nearly as possible, and having only gentle and declivities, for a greater distance on a road nearly level, is productive of less expense of animal strength, than a lesser distance passing over considerable elevations. Hence the necessity of carefully selecting, examining and levelling every proposed line of road...

Drainage is an affair of primary importance in road-making, and requires much skill to execute it in a proper manner. The ditch ought to be on that side of the road whence the flood water flows toward the road. Its capacity should be regulated by the quantity of water which it has to convey, and the distance to which it has to carry it before reaching a lateral outlet. Lateral outlets should be capacious, and, if possible, frequent. The strata of the soil should be carefully studied, and means used to convey all water from springs, however small, into the ditch. It may even be necessary to carry the process of drainage far beyond the area of the road, but no general rules will apply to such a case.

Thomas Roy (1841)

PREFACE

This report endeavours to address two main, not necessarily incompatible objectives, namely (i) to summarize and critique the methods and equipment used in designing and ~~costricting~~ constructing off-highway haulroads by a number of operating mines in Western Canada and (ii) to present design guidelines and construction procedures for producing safe, efficient haulroads for heavy vehicles. The summary of current practice outlined is by no means exhaustive but is based, nonetheless, on interviews with mine operators, completed questionnaires on the methods used, case histories from published literature and consultant experience with mine haulroads in Canada and abroad.

In the compilation of the design guidelines, every attempt has been made to present the information concisely and accurately and portray state-of-the-art practice for design, construction and maintenance of mine haulroads. It remains the responsibility of the designer, however, to satisfy himself as to the applicability of the material herein to his project and to ensure that the parameters used for road loading, traffic volume, hauler characteristics, subgrade conditions, construction material properties, etc. are correctly evaluated and implemented for the specific site conditions at his mine.

For the most part, SI units of measurement are used in the report. Since many of the charts and figures referenced in the guidelines utilize English units, however, revisions were not considered expedient and the English system was retained.

TABLE OF CONTENTS

PAGE

Title Page
Letter of Transmittal
Executive Summary (i)
Prologue (ii)
Preface (iii)
Table of Contents (iv)

1.0 INTRODUCTION 1-1

2.0 MINES CANVASSED 2-1

- 2.1 GENERAL 2-1
- 2.2 CLIMATIC CONDITIONS 2-1
- 2.3 GEOLOGICAL SETTING 2-1
- 2.4 MINE STATISTICS 2-3
- 2.5 COST OF ROAD CONSTRUCTION AND MAINTENANCE 2-7

3.0 CRITIQUE OF CURRENT DESIGN METHODS 3-1

4.0 GUIDELINES FOR HAULROAD DESIGN 4-1

- 4.1 HAULROAD ALIGNMENT 4-1
  - 411 GENERAL 4-1
  - 412 HAULER STOPPING DISTANCE 4-1
  - 413 SIGHT DISTANCE 4-5
  - 414 HORIZONTAL ALIGNMENT 4-5
  - 415 SUPERELEVATION RUNOUT 4-7
  - 416 ROAD WIDTH ON CURVES 4-9
  - 417 VERTICAL ALIGNMENT 4-9

TABLE OF CONTENTS (Cont'd)

PAGE

418 VERTICAL CURVES 4-12

419 COMBINATION OF HORIZONTAL AND VERTICAL ALIGNMENT 4-13

4.2 HAULROAD CROSS-SECTION 4-15

421 GENERAL 4-15

422 ROAD FILL THICKNESS 4-16

423 CBR METHOD 4-16

424 COMPACTION REQUIREMENTS 4-19

425 SURFACE COURSE 4-22

426 ROLLING RESISTANCE 4-24

4.3 HAULROAD TRAFFICABILITY 4-28

431 GENERAL 4-28

432 DRAINAGE REQUIREMENTS 4-29

433 WEARING SURFACE 4-31

4.4 SUBGRADE STABILIZATION MEASURES 4-38

441 GENERAL 4-38

442 GEOTEXTILES 4-39

443 GEOGRIDS 4-40

Step 1 - Site Preparation 4-41
Step 2 - Placing and Overlapping Geogrids 4-41
Step 3 - Tensioning and Pinning 4-42
Step 4 - Dumping and Spreading 4-42
Step 5 - Compaction 4-43

444 GEOCELLS 4-53

4.5 DUST SUPPRESSANTS

TABLE OF CONTENTS (Cont'd)

PAGE

5.0 HAULAGE EQUIPMENT 5-1

5.1 EQUIPMENT SPECIFICATIONS 5-1

511 TIRES 5-1

512 EQUIPMENT MODIFICATIONS 5-4

5.2 EQUIPMENT MAINTENANCE 5-7

521 PREVENTATIVE MAINTENANCE 5-7

522 MAINTENANCE COSTS 5-9

6.0 GOVERNMENT REGULATIONS 6-1

6.1 HAULROAD DESIGN 6-1

6.2 HAULER EQUIPMENT - SERVICE, PARKING & DYNAMIC BRAKES 6-2

6.3 HAULER EQUIPMENT - TIRES 6-14

6.4 HAULROAD - TRAFFIC CONTROLS 6-15

7.0 LIST OF REFERENCES 7-1

APPENDICES

APPENDIX A - LIST OF SYMBOLS
APPENDIX B - METEOROLOGICAL CONDITIONS AT DIFFERENT MINESITES
APPENDIX C - EXXON GEOTEXTILE DESIGN MANUAL FOR UNPAVED ROADS
APPENDIX D - DESIGN EXAMPLE USING TENSAR GEOGRIDS

TABLE OF CONTENTS (Cont'd)

PAGE

TABLES

Table

2-1 Producing Surface Mines in Western Canada
2-2 Weather Conditions at Different Minesites
2-3 Types of Stripping and Mining Equipment
2-4 Haulage Equipment
2-5 Haul Road Length
2-6 Annual Traffic Loading on Ex-Pit Roads
2-7 Annual Traffic Loading on In-Pit Roads
2-8 Traffic Loading and Expected Road Life
2-9 Haulroad Geometry
2-10 Typical Road Cross-section & Water Crossing Construction
2-11 Road Construction and Maintenance Equipment
2-12 Materials used for Road Construction
2-13 Materials used for Road Wearing Surface
2-14 Symptoms of Haulroad Deterioration
2-15 Causes of Road Surface Deterioration
2-16 Measures Taken to Improve Road Trafficability
2-17 Measures Used for Dust Suppression
2-18 Road Maintenance Frequency
2-19 Traffic Control Installations

4-1 Recommended Superelevations for Horizontal Curves
4-2 Minimum turning Radii for Various Haulers
4-3 Design Widths for Horizontal Curves
4-4 Presumptive Bearing Capacity of Various Materials
4-5 Haulroad Section Based on CBR Chart
4-6 Typical Road Adhesion Coefficients
4-7 Rolling Resistance Model Tests on Towed Wheels
4-8 Rolling Resistance for Various Types of Road Surface
4-9 Advantages & Disadvantages of Various Road Surfacing Materials
4-10 Critical Roadfill Thickness for Loaded Trucks
4-11 Recommended Grading for Granular Surface Course
4-12 Summary of Soil Improvement Methods
4-13 Properties of Typical Tensar Geogrids
4-14 Guide for Estimating Subgrade Soil Strengths
4-15 Guide for Estimating CBR by Soil Classification

5-1 Typical Maintenance and Service Costs for Various Types of Equipment
5-2 Owning and Operating Costs for Caterpillar Off-Highway Trucks & Tractors

TABLE OF CONTENTS (Cont'd)

PAGE

FIGURES

Figure

2-1 Location of Surface Mines in Western Canada
2-2 Extreme Temperature Variations at Western Mines
2-3 Aggregate Stripping Ratios for Coal & Tarsands Operations
2-4 Variations in Haulroad Traffic Loading
2-5 Road Loading vs. Expected Service Life

4-1 Visability of 33-15C Titan Hauler Operator
4-2 Stopping Distance Characteristics for Haulers of Various Weights
4-3 Sight Distance Diagrams for Horizontal and Vertical Curves
4-4 Road Superelevation vs. Vehicle Speed
4-5 Procedure for Computing Road Width on Horizontal Curves
4-6 Vehicle Performance Chart - Ascending Grades
4-7 Vehicle Performance Chart - Descending Grades
4-8 Effect of Grade Reduction on Stopping Distances
4-9 CBR Curves
4-10 Example of CBR Method
4-11 Rolling Resistance Tests - Towed Wheel
4-12 Moisture Content vs. Trafficability
4-13 Thickness Requirements for 9,000 lb Dual Wheel Loads
4-14 Thickness Requirements for 12,000 lb Dual Wheel Loads
4-15 Thickness Requirements for 32,000 lb Single Wheel Loads
4-16 Thickness Requirements for 60,400 lb Single Wheel Loads
4-17 Thickness Requirements for 46,000 lb Dual Wheel Loads
4-18 Thickness Requirements for 100,000 lb Dual Wheel Loads
4-19 Pressure Isobars for Square and Long Footings

1.0 INTRODUCTION

The purpose of this study was to outline objective procedures, thereby potentially alleviating the subjective elements involved, for the design of surface mine haulroads. The objective approach should result in an economic design compatible with the haulage fleet characteristics and available construction materials at a given mine site as well as the applicable requirements of the regulatory authority having jurisdiction. Since haulage costs, including those for both roads and equipment, typically range from 20% to 30% of total mining costs in western Canadian surface mines, production economics and competition in world markets dictate that this cost component be kept to a minimum. The problem is presently addressed by mines on an individual basis considering their own specific conditions and operations.

Particular objectives of this study included the following:

- a literature review of state-of-the-art design methods for surface mine haul roads and the rationale for the methods;

- a review of the procedures and calculations used in western Canadian mines, highlighting methods used to compensate for such typical conditions as low quality construction materials, high traffic volumes, large axle loads, harsh climatic conditions, etc.;

- a critique of the suitability of design criteria currently used for haul road construction, identifying where improvements could be made to current techniques or to the databases on which they depend;

- an investigation of construction materials and maintenance techniques that may be used in future such as binding and traction additives, earth reinforcement and geotextiles/ geosynthetics;

- recommendations for suitable testing methods to evaluate the performance of a mine haulroad to compare with that predicted by the design.

To obtain the required information on current design and construction practice for haulroads, a detailed questionnaire was prepared and forwarded to those mine operators who wished to participate in the study. Subsequent to issuing the questionnaire, site visits to participating mines were scheduled to discuss general and site specific aspects of haulroad design as practised at the host mine as well as to inspect first hand the haulroads and haulage fleet at each site. Information solicited from each site included:

- haulroad design and maintenance techniques that have been employed and any techniques that mine operators are considering for future use;

- road construction materials used at the mine with available data on typical grain size distribution, compaction characteristics, placement procedures etc.;

- traffic volume, types of vehicles comprising the haulage fleet, empty and loaded vehicle weights;

- road performance data including rolling resistance, traction, bearing capacity, roughness etc.;

- haulage fleet maintenance costs, especially those costs related to road conditions;

- types of road maintenance equipment and frequency of use;

- chronic haulroad problems which affect road trafficability, vehicle productivity or availability.

The study was funded by Supply and Services Canada, a branch of the Department of Energy, Mines and Resources, and administered by Dr. R. Kolada, CANMET, Devon, Alberta.

2.0 MINES CANVASSED

2.1 GENERAL

A listing of the currently producing surface mines in Western Canada is given in Table 2-1. The thirteen mines participating in this program are denoted by an asterisk in the table and are located geographically on Fig. 2-1.

2.2 CLIMATIC CONDITIONS

The climatic conditions at the various mines are typical of the northern hemisphere exhibiting cold winters and warm to hot summers. Local variations in both temperature and precipitation occur depending on site elevation, latitude and prevailing wind direction. The range in extreme monthly temperature at five minesites, selected to represent typical conditions within the geographical area, is shown on Fig. 2.2. Weather conditions at the different minesites are summarized in Table 2-2. More detailed meteorological records of precipitation and temperatures for different mines are included in Appendix B.

2.3 GEOLOGICAL SETTING

Each of the thirteen mines canvassed is located in one of two distinct geological provinces in Western Canada, namely the western plains geological area or the Cordilleran foothills region of Alberta and British Columbia. The plains area is characterized by flat lying sediments with regional dips rarely exceeding a few degrees southwest, low tectonic history but surface-sculptured by past glacial activity and relatively young, poorly indurated formations of Tertiary and Cretaceous age overlain by clay-rich Pleistocene till. Glaciation has resulted in relatively minor bedrock disturbance which is limited to faulting, folding, fracturing and brecciation to depths rarely exceeding 50 m. Besides a veneer of till and local deposits of lacustrine sediments, coal and tarsand overburden comprises varying thicknesses of stratified and interbedded sandstone, siltstone, claystone and shale units predominately formed in non-marine and deltaic environments. Bentonitic clays derived from the chemical weathering of volcanic ash, which originated from pre-historic eruptions in the Rocky Mountain Ranges, commonly occur in both indurated and unconsolidated deposits either as continuous layers or as the cementing matrix in rock formations. Landform within the plains geological province varies from flat to gently rolling with elevations ranging from about 300 m to 800 m above sea level.

The Cordilleran sequences within the Rocky Mountain chain, on the other hand, are structurally formed, primarily by thrust faulting of older formations eastwards up and over younger rocks. Topographic relief between the valley bottoms and mountain peaks can vary from 1000 m to over 2500 m in elevation. A thin layer of residual soils often occurs in the upland areas, whereas morainal, fluvial, lacustrine and talus deposits can be present along the mountain slopes and valley floors. As a result of past tectonic activity, formation bedding is often tilted, folded and distorted and individual rock units are more highly indurated than plains deposits. The bentonite content in fine-grained sediments is relatively minor although fault zones often contain weak, Kaolinite-rich gouge associated with shear displacements with shale and siltstone sequences. Very hard igneous intrusives and cemented conglomerates occur locally as dykes or interbeds within the host formation.

2.4 MINE STATISTICS

The aggregate 1987 production of run-of-mine coal from the eleven surface coal mines canvassed is approximately 33 million tonnes of which about 15 million tonnes, or 45%, is metallurgical coal, the remainder being thermal coal. The two tarsands operations produced an estimated 140 million tonnes of tarsands in 1987.

The overall stripping ratios for coal and tarsands mines, respectively, are notably different as illustrated on Fig. 2-3. The coal operations collectively have an aggregate overburden to product ratio of 5.25 bcm/tonne whereas the tarsands mines enjoy a more favourable average strip ratio of 0.46 bcm/tonne. In 1987, overburden and interburden spoil from the eleven coal mines totalled some 180 Mbcm and the volume of spoil from tarsands operations was approximately 60 Mbcm. Types of stripping and mining equipment currently in use are listed in Table 2-3 and the various makes and models of equipment comprising present haulage fleets are shown in Table 2-4.

The cumulative lengths of haul roads constructed at all mines are approximately 50 km of in-pit or temporary roads and 180 km of ex-pit or longterm roads. Road lengths, itemized according to type of material transported, are approximately as shown in Table 2-5.

The estimated fleet traffic loading imposed on the haulroads at each mine over a 12 month period was computed as the product of the vehicle weight (loaded plus empty), traffic frequency and operating hours per year. The results of the computations are tabulated for ex-pit and in-pit roads, respectively, in Tables 2-6 and 2-7, and depicted as bar charts on Fig. 2-4. Traffic loading is compared with the expected road service life, as denoted by various mine operators, in Table 2-8. By plotting anticipated service life against road loading (Fig. 2-5), empirical upper bound envelopes can be constructed which can be assumed, for practical purposes, to represent the maximum road life for a given traffic intensity before major road repairs are required. The straight line corresponds to a road constructed of better quality materials generally available at mines in the Cordilleran region, whereas the lower curve represents roads constructed with weakly cemented sedimentary rocks and clay till native to the western plains.

Table 2-9 displays the haulroad geometry used at the canvassed mines and includes, when constructed, run-away lane configurations and height of safety berms along the road shoulders.

Typical construction materials and thicknesses used for haulroad base and surface courses, along with methods employed at water crossings, are summarized in Table 2-10. Equipment used for road construction and maintenance is listed in Table 2-11.

To minimize costs, mine operators utilize to the fullest extent possible locally available materials for construction of road embankments. Materials used include natural deposits (eg. till, sand and gravel), spoil from stripping operations, crushed or blasted rock, and other waste products from the site such as coal ash and tarsand rejects (see Table 2-12). Unless the road can be located on competent bedrock, road fill is generally topped with a surface wearing course of fine crushed rock, coarse gravel or other durable materials as listed in Table 2-13. Four mines currently have a crusher on site and a fifth is planning to purchase one in the near future.

Symptoms and causes of road deterioration, outlined in Tables 2-14 and 2-15, respectively, reportedly arise from either poor quality construction materials, inadequate compaction during fill placement, climatic conditions, high groundwater levels, vehicle spillage or a combination of the above. Methods used at the various mines to improve haulroad trafficability emphasize maintenance procedures (see Table 2-16) whereas, in some cases at least, maintenance costs could well be reduced by improved design and construction practice.

A problem common to all mines visited is dust formation resulting from haulroad traffic, dusty conditions being most severe during the hot, dry summer months. Dust suppression by continuous water sprinkling is generally used at each site. However, other methods which have been tried with mixed success are sprinkling roads with used engine oil or locally available saline groundwater, various chemical additives, and application of potash obtained at one minesite by return runs from thermal coal deliveries to a potash plant in Saskatchewan. Chemical additives include calcium lignosulphonate, calcium chloride and Bio-Cat 300-1. A summary of dust suppressants used is given in Table 2-17.

To improve traction on winter roads, snow removal, scarifying and grit application are generally employed. Grit materials used at various mines vary as follows:

Material	Size (mm)
Crushed rock	50-19
Crushed rock	19-9
Crushed rock	(not available)
Sand & crushed rock	(not available)
Pit-run gravel	(not available)
Sand	(not available)
Crushed limestone	(not available)

Only three mine operators indicated that a preventative maintenance program for haulroads was in effect at their mines. The frequency of road maintenance, categorized as cleaning and grading, repair work and dust suppression, is given for all mines in Table 2-18.

The number and type of safety and traffic control installations varied at each minesite (see Table 2-19), although most mines had stop signs or traffic lights at major intersections, speed limit and traffic control signs, limited access designators and roadside safety berms. In addition most mountain mines have runaway lanes installed on hills at less than 400 m intervals along the road alignment or at ~~grade separations less~~ than 30 m.
elevation changes of not more

Equipment problems attributable to poor haul road conditions include:

- reduced tire life - estimated to vary from a low of 2000 hr to a maximum of 8000 hrs as reported by four different mines located in mountainous terrain. Most mines, however, do not maintain records of tire life as their tires are leased;

- increased fuel consumption - on roads with high rolling resistance or dusty conditions;

- increased wear on moving parts, bearings, engine, etc. under extreme dust conditions;

- one instance of a twisted frame which occurred when a loaded truck was negotiating a 16% grade on the inside of a switchback.

- risk of tire damage and increased wear on shocks and springs when traversing rough, bumpy roads.

2.5 COST OF ROAD CONSTRUCTION AND MAINTENANCE

Costs of road construction and maintenance as well as equipment operating costs were considered by most mines to be confidential. However, order of magnitude costs provided by a few mines were as follows:

	Range of Costs
o Haul Road Construction - $M/km	0.1 - 1.0
o Haulage Cost (% of Total Mining Cost) - %	3 - 67
o Road Maintenance (% of Haulage Cost) - %	3 - 25
o Tire costs (% of Haulage Cost) - %	11
o Tire Costs - $/op.hr.	1.33
o Fuel - $/op.hr	10 - 19
o Oil and grease - $/op.hr	0.53 - 3.00
o Labour Costs - Equipment Operator - $/hr	20 - 27
o Labour Costs - Fleet Maintenance - $/hr	30

The wide range in costs reflects, in part, the variation in topography, quality of road construction materials available, road length, remoteness of location and traffic loading intensity at different minesites.

PART 3

CRITIQUE OF CURRENT DESIGN METHODS

To Come

4.0 GUIDELINES FOR HAULROAD DESIGN

4.1 HAULROAD ALIGNMENT

411 GENERAL

As reiterated by KAUFMAN & AULT (1977), all geometric elements of haulroads, insofar as it is economically feasible, should be designed to provide safe, efficient travel at normal operating speeds. The ability of the vehicle operator to see ahead a distance within which he can stop the vehicle is a primary consideration. Vehicle stopping distance is one component that must be evaluated for each type of vehicle in the haulage fleet to allow the designer to establish horizontal and vertical road alignment. Associated with the vehicle stopping distance is the operator "sight distance". The area visible to the operator of a 33-15C Titan hauler, for example, is illustrated on Fig. 4-1. It is imperative that everywhere along the road alignment the sight distances be sufficient to enable a vehicle travelling at the posted speed to stop before reaching an obstruction or hazardous situation on the road ahead. On vertical curves the sight distance is limited by the road surface at the crest. On horizontal curves, sight distance is limited by steep rock cuts, trees, structures, etc. The distance measured from the driver's eye to the hazard ahead must always be equal to or greater than the distance required to safely stop the vehicle.

412 HAULER STOPPING DISTANCE

Specifications for brake performance provided by most truck manufacturers are generally limited to an illustration of the speed which can be maintained on a downgrade by use of dynamic or hydraulic retardation through the drive components. Although this is an efficient method of controlling descent speed, it does not replace effective service brakes. Should the retardation system fail, wheel brakes become the second line of defence to prevent vehicle runaway.

Recognizing the need for effective brake performance standards, the Society of Automotive Engineers (SAE) has developed test procedures and minimum stopping distance design criteria for different weight categories of large, off-highway trucks.

According to KAUFMAN & AULT (1977), SAE delineates the following maximum permissible service brake stopping distances for vehicles of different weight categories travelling at an initial speed of 20 mph on a dry, level, clean concrete surface:

Category	GVW (lb)	Maximum Stopping Distance (ft)
1	less than 100,000	60
2	100,000 - 200,000	90
3	200,000 - 400,000	125
4	more than 400,000	175

While the majority of hauler manufacturers equip their products with brake systems that meet or exceed these criteria, it is uncertain how brake performance may vary with changes in grade, road surface conditions, initial speed, or, indeed, with brake system wear or contamination with dust, oil, water, etc.

To assess stopping distances for different grades and speeds in each SAE test weight category, the authors developed, based on the above SAE stopping distance limitations, a mathematically deduced empirical formula:

$$SD = \left[(0.5\,gt^2)\sin\theta + V_o t\right] + \left[\frac{gt\sin\theta + V_o}{2g\,(U_{min} - \sin\theta}\right]^2 \quad \ldots.(1)$$

Where:

SD = stopping distance (ft)
g = gravitational pull (32.2 ft/sec/sec)
t = elapsed time between driver's perception of the need to stop and the actual occurrence of frictional contact at the wheel brakes (sec)
θ = angle of descent (degrees)
U_{min} = coefficient of friction at the tire-road contact area
V_o = vehicle speed at time of perception (ft/sec)

The factor, t, is actually composed of two separate time intervals, t_1 and t_2. Component t_1 is the elapsed time for brake reaction due to pressure build-up in the brake system after the brake pedal is depressed and the brake mechanism is actuated to effectively exert a retarding force on the wheels. Typical values of brake reaction time suggested by SAE are as follows:

Weight Category	GVW (lb)	t_1 (sec)
1	less than 100,000	0.5
2	100,000 - 200,000	1.5
3	200,000 - 400,000	2.75
4	more than 400,000	4.5

The second component of t, designated t_2, is driver reaction time, i.e. the time between driver perception of a hazard and when his foot actually begins to depress the brake pedal. The authors indicate a reasonable value of t_2 is 1.5 sec.

The factor U_{min} was evaluated from the following expression:

$$U_{min} = \frac{V^2}{2\,gS} \qquad \text{....(2)}$$

Where:

V - A SAE test velocity of 29.33 ft/sec (20 mph)

g - 32.2 ft/sec/sec

S - stopping distance computed by subtracting (29.33 x t_1) from the SAE recommended stopping distance for each weight classification

Substitution of the various SAE stopping distances and t_1 factors for each weight category into equation (2) yielded and average minimum achievable coefficient of friction, U_{min}, of 0.3 and a corresponding vehicular deceleration of about 9.66 ft/sec/sec.

Based on equations (1) and (2), stopping distance curves were developed for different grades, speeds and vehicle weight category. The authors concede, however, that these formulae do not account for brake fade due to heat buildup which constant brake application may induce.

Because of the difficulty involved in expressing brake fade in mathematical terms, the authors adopted a maximum braking distance to preclude fade based on empirical test data from the British Columbia Department of mines and Petroleum Resources (Dawson, 1975). The empirical test data were derived from more than 1,000 truck stopping-distance tests conducted at operating mines in British Columbia. The stopping distance curves generated by the authors are reproduced on Fig. 4-2. Also shown on each of the curves is a straight line increasing with velocity which represents the limiting distance required to prevent brake fade.

KAUFMAN & AULT recommend that these curves, which are mathematically derived and not based on the results of actual field tests, be used as guidelines in the preliminary planning stage of road design. Before actual road layout begins, the designated hauler manufacturer should be contacted to verify the service brake performance capabilities of their trucks without assistance from dynamic or hydraulic retardation systems.

Recent, trial service brake stopping tests for a Caterpillar 785 hauler (GVW = 508,000 lb) on a 9% downgrade indicated a stopping distance of 220 ft from an initial speed of about 37 mph (HOLMAN, 1989). The tests were conducted in accordance with SAE J1473 procedures which require the following stopping distances for this vehicle weight on a 9% grade:

Speed		Stopping Distance	
(mph)	(Km/hr)	(ft)	(m)
9.3	15	33	10
21.7	35	164	50
31.1	50	328	100
37.3	60	492	150
40.4	65	574	175

In addition, MACMILLAN (1989) reports similar tests on the new 830E Haulpack (GVW = 832;000 lb) wherein a stopping distance of 275 ft was measured on a 10.4% downgrade.

413 SIGHT DISTANCE

The relationship between operator sight distance and vehicle stopping distance is illustrated on Fig. 4-3 for safe and unsafe conditions.

414 HORIZONTAL ALIGNMENT

Horizontal haulroad alignment addresses the required width and superelevation of the road to enable vehicles to safely negotiate around curves at a given speed taking into account sight distance and minimum vehicle turning radius. The cost implications of physical constraints to construction, such as quantity of rock excavation necessary, must also be considered in laying out the curve. For example, to construct a road around a prominent rock nose in mountainous terrain, the designer has to weigh the cost of rock excavation for a large radius curve which can be negotiated safely at, say 25 mph, against a tighter curve with minimal rock excavation but which requires vehicles to slow to 10 mph, thereby increasing vehicle cycle time and penalizing productivity during the life of the road.

It is emphasized, however, that operational safety should not be compromised and that any relaxation of specifications to mitigate construction costs should be accompanied by a corresponding reduction in operating speed.

To reduce centrifugal forces when a hauler is travelling around short radius curves, the outside edge of the road should be raised or superelevated above the inside edge. The expression for computing superelevation is:

$$e = \frac{V^2}{15R} - f \qquad \ldots.(3)$$

Where:

e = superelevation (ft/ft)

V = vehicle speed (mph)

R = curve radius (ft)

f = coefficient of friction between the tires and the road surface, termed side friction factor (dimensionless)

Ideally, tire wear would be reduced and steering would be effortless if road superelevation was just equal to the vehicle weight component, ($V^2/15R$). There is, unfortunately, a practical limit to which a road can be superelevated since high cross-slopes around curves can, for slow moving vehicles, cause higher loads on the inside wheels, increased tire wear, potential bending stresses in the vehicle frame and, on ice covered surfaces, vehicle sliding down the cross-slope.

Field trials have demonstrated (AASHO, 1965) that, for short-radius curves, the side friction factor increases as vehicle speed decreases, and thus the required superelevation computed as per equation 3 is small and within the range of cross-slopes generally used for surface drainage. This information, along with the fact that short curves afford little opportunity for providing superelevation and runout, lead to the formulation of the recommended superelevations for different speeds and curve radii given in Table 4-1(a). A somewhat broader range of superelevations, however, is used in road design at Syncrude Mine (see Fig. 4-4) and recommended by Caterpillar (1988) (See Table 4-1(b)).

415 SUPERELEVATION RUNOUT

Changes between a normal road cross-section and a superelevation section should be gradual to assist the driver in manoeuvring the vehicle through the curve. KAUFMAN & AULT recommend that this portion of the road, termed the transition or runout length, be apportioned one-third to the curve and two-thirds to the tangent. Runout lengths vary with vehicle speed and total cross-slope change and suggested guidelines are as follows:

Vehicle Speed (mph)	Maximum Change in Cross-Slope per 100 ft of Road Length (%)
10	8
15	8
20	8
25	7
30	6
35 and above	5

The use of this tabulation can best be illustrated by an example. Suppose a vehicle is travelling at 35 mph on a straight road with a cross-slope of 4 % to the right. It encounters a curve to the left with a superelevation of 6 % to the left, thus the total change in cross-slope is (4 + 6) or 10 %. For 35 mph, the recommended change in cross-slope is 5 % thus the total runout length should be (10/5) x 100 = 200 ft. One third of this length (67 ft) should be fitted to each end of the curve and the remainder (133 ft) applied to each tangent at the beginning and end of the curve. A smooth spiral transition section not only allows vehicles to negotiate curves more easily but also minimizes twist on the vehicle chassis.

To ensure roads are constructed and maintained with smooth runout sections, thus minimizing the potential for metal fatigue from frame twist, a practical apparatus has been developed to directly measure induced twist as the road is travelled (DESLANDES & DICKERSON, 1989). The device consists of a trailer which is coupled to a hauler through a tensionally rigid joint (Hookes joint). The track of the trailer and the effective wheelbase between the rear axle of the truck and the trailer axle are adjustable to allow presetting and matching with those of the truck being used. Trailer tires are sized to match the truck tires. By such an arrangement, the angular distortions between the rear axle and trailer axle mimic those induced in the truck frame by twist of the truck tire - road surface contact points. Twist is resolved at a rotating joint located on the trailer drawbar and a direct measure of twist is provided on a strip chart recorder mounted in the driver's cab. A digital pulse indicator installed in one trailer wheel is used to increment the recorder to make the chart distance proportional to truck travel distance. By installing numerous strain gauges at crucial points on the truck frame, the authors were able to record speed, twist and strain and hence correlate frame response to twist measurements accumulated by the test trailer. They concluded that very good correlations between measured twist and frame strain were obtained. Since the trailer is of simple construction, can provide results in real time, doesn't require complex computer processing of data, and causes minimal disruption of normal mine operations, it appears to be a useful device for monitoring roughness and unevenness of haulroad surfaces on curves and elsewhere.

416 ROAD WIDTH ON CURVES

Switchbacks or other areas on haulroads requiring sharp curves must be designed to take into consideration the minimum turning radius of the haulers. Typical minimum turning radii for vehicles in the different weight categories, along with minimum U-turn radii for Terex and Kress bottom dumps, are included in Table 4-2.

The procedure for determining road width on curves to account for vehicle overhang, lateral clearance between passing haulers and extra width allowance to accommodate difficult driving conditions on curves is shown on Fig. 4-5. Since curve widths vary for vehicles in each weight category and for different curve radii, KAUFMAN & AULT recommend the widths given in Tables 4-3(a) and 4-3(b) for single unit and articulated haulers, respectively. These tables should be used as guidelines to establish the minimum width of road around horizontal curves.

417 VERTICAL ALIGNMENT

Vertical alignment in road design is defined as the judicious selection of grades and vertical curves that permit adequate stopping and sight distances on all segments of the haulroad. Recommended design procedures for establishing maximum grades and minimum radii for vertical curves are outlined in the following paragraphs.

Maximum and Sustained Grades

Maximum practical grades are determined, not only by safe vehicle stopping distances (see Fig. 4-2), but also by terrain characteristics and consideration of hauler productivity. If grades are steep, haulers have to decrease speed on descent to ensure safe stopping distances and ascending equipment requires frequent gear reduction and consequent speed losses. Such changes in velocity result in lost production time, additional fuel consumption, increased mechanical wear and higher maintenance costs. The road designer must also balance the projected savings of enhanced productivity on flat grades against the capital cost of excavation and embankment fill to achieve these flat grades. The types of vehicles in the haulage fleet and the performance characteristics of each type must be known to the designer as well. KAUFMAN & AULT present a number of charts, reproduced herein as Figs. 4-6, 4-7 and 4-8, to illustrate the interrelationships between road grade, GVW, vehicle speed and vehicle performance. The impact of grade on vehicle performance when ascending a grade can be demonstrated by inspection of the typical performance chart on Fig. 4-6. Different symbols have been superimposed on the chart to delineate attainable speed for a vehicle operating on a 5% and 10% grade under loaded and unloaded conditions.

It is apparent from Fig. 4-6 that a reduction in grade significantly increases a vehicle's attainable uphill speed. Thus, haulage cycle times, fuel consumption, and stress on mechanical components, which results in increased maintenance, can be minimized to some extent by limiting the severity grades.

By relating the 10% to 5% grade reduction to the stopping-distance charts in the previous section, it can be seen that safety and performance are complementary rather than opposing factors. To demonstrate this fact, a reproduction of the stopping-distance chart for vehicles in the 100,000 to 200,000 pound category is shown on Fig. 4-8. As indicated by the superimposed lines on the chart, a 5% grade reduction corresponds to a 6 mph increase in descent speed without materially exceeding the stopping distance limitations.

Since it would not be feasible to establish one optimum maximum grade to suit all haulers, it is therefore the responsibility of the road designer to assess the braking and performance capabilities of his particular haulage fleet and, based on these data, determine whether available capital permits construction of ideal grades or requires steeper grades at the sacrifice of haulage-cycle time. The only guidelines for maximum grade that can be established with certainty are those set forth by the regulatory authorities in whose jurisdiction the haulroad is located. In the United States, the majority of States have established 15% as the maximum grade, while a few States allow grades up to 20%.

Length of sustained grades for haulage road segments are yet another factor that must be considered in vertical alignment. Many mine operators have found optimum operating conditions reflected on maximum sustained grades no greater than 7% to 9%. Also, many State laws and regulations establish 10% as a permissible maximum sustained grade. However, this does not mean that vehicles cannot be safely operated on more severe downgrades.

Significant improvements have been made in controlling downhill speed through hydraulic and dynamic retardation of drive components (MACMILLAN, 1989; HOLMAN, 1989; JOHNSON, 1989). Charts similar to Fig. 4-7 are available for most modern haulage equipment and illustrate their controllability on downgrades. As indicated by the example, this particular vehicle is advertised as being capable of descending a 15% grade at 8 mph if geared down to second range. Thus, the vehicle can be kept to a speed that is within the safe emergency braking limitations. The chart does not, however, specify the retardation limits in terms of time or length of sustained grade.

All retardation systems function by dissipating the energy developed during descent in the form of heat. In hydraulic systems, this is accomplished through water-cooled radiators; the dynamic method generally relies on air-cooled resistance banks. It is possible to overheat either system if the combination of grade and length is excessive.

Considering the foregoing factors, it is reasonable to accept 10% as maximum safe sustained grade limitation (KAUFMAN & AULT, 1977).

418 VERTICAL CURVES

Vertical curves are used to provide a smooth transition from one road grade to another. Lengths of vertical curves should be adequate to drive comfortably and provide ample sight distances at the designed vehicle speed. The authors recommend the following expressions be used to compute curve lengths:

i) For S greater than L

$$L = \frac{2S - 200\,(\sqrt{h_1} + \sqrt{h_2})^2}{A} \qquad \ldots.(4)$$

ii) For S less than L

$$L = \frac{AS^2}{100\,(\sqrt{2h_1} + \sqrt{2h_2})^2} \qquad \ldots.(5)$$

Where:

L - length of vertical curve (ft)
S - attainable vehicle stopping distance (ft)
A - algebraic difference in grades (%)
h_1 - height of driver's eye above ground (ft)
h_2 - height of object above road surface (ft)

The height of object above the road surface should be taken as 0.5 ft to cover such possibilities as a prostrate figure, an animal or dropped gear on the road surface.

Generally, curve lengths greater than the computed minimum are desirable as they result in longer sight distances. Excessive lengths, however, can result in long, relatively flat sections which may lead to soft spots or potholes unless adequate drainage is provided. In any event, vertical curve lengths less than 100 ft should be avoided.

419 COMBINATION OF HORIZONTAL AND VERTICAL ALIGNMENT

In the design of haulroads, horizontal and vertical alignments should complement each other. Potential problem situations to be avoided are:

- sharp horizontal curves at or near the top of a hill since the driver has difficulty perceiving the curve, especially at night or in foggy weather. If a horizontal curve is necessary, it should be started well in advance of the vertical curve;

- sharp horizontal curves near the bottom of hills or following a long sustained downgrades where haulers are normally at their highest speed;

- short tangents and varying grades, especially on multi-lane roads;

- intersections near the crest of vertical curves or sharp horizontal curves. Intersections should be as flat as possible with sight distances being considered in all four quadrants.

COLLINS et al (1986) summarize the salient points to be considered when designing haulroad alignments as:

- the operator should, at all times, be able to see ahead a distance at least equal to the vehicle stopping distance;

- sharp horizontal curves should be avoided at the top and at the bottom of ramps;

- intersections should be made as flat as possible and should not be constructed at the top of ramps;

- for a two-lane haulroad, the minimum width should be 3.5 times the width of the largest truck in the haulage fleet. To safely negotiate sharp curves, this width should be increased by allowing for passing lanes and safety berms;

- for good drainage, road surface cross-slopes should be 1/2 in per foot and ditches should have "V" configurations with side slopes not exceeding 2H:IV;

- horizontal curves should be superelevated by about 4% to 6% depending on the curve radius and equipment speed;
- the curve radius should exceed the minimum turning radius of the haulage equipment.

4.2 HAULROAD CROSS-SECTION

421 GENERAL

The main components which form a road cross-section are:

- subgrade
- sub-base
- base course
- surface course

The subgrade is the existing ground surface on which road fill is placed. The sub-base, base course and surface course are layers of fill of increasing quality which are successively placed above the subgrade to form the embankment fill. Subgrade can consist of native in-situ soil or rock, previously placed landfill or mine spoil, muskeg, marsh or other existing surface over which a road is to be placed. Where the subgrade comprises hard, sound rock or dense, compact gravel, little or no fill may be necessary as haulers can travel on the subgrade surface. At the other end of the spectrum, soft clays and muskeg will require substantial quantities of fill to help spread the heavy wheel loads and prevent rutting, sinking or overall road deterioration. Such adverse conditions, if allowed to occur, pose a serious threat to vehicular controllability and create unsafe haulage road segments.

422 ROAD FILL THICKNESS

The ability of a given subgrade to support vehicular or other loading is termed its bearing capacity. Typical or presumptive bearing capacity values for different subgrade materials are listed in Table 4-4. However, determining the bearing capacity of a particular soils for haulroad design is a detailed procedure that should be carried out by a qualified geotechnical engineer. Since many haulers operate with tires inflated to 80 psi or more, it can be seen from Table 4-4 that any material weaker than soft rock will require additional fill material to establish a stable road base. The designer must therefore determine the thickness and quality of additional material that should be placed over the subgrade to adequately support the applied traffic loads.

423 CBR METHOD

One of the most widely used methods of computing required fill thickness is the California Bearing Ratio (CBR) method. This approach characterizes the bearing capacity of a given soil as a percentage of the bearing capacity of a standard-crushed rock, the ratio of capacities being referred to as the CBR for the given soil. Empirical curves, known as CBR curves, relate the required fill thickness and applied wheel load to the CBR value. This system, originally developed in 1942, continues to be used by highway engineers for evaluating overall roadfill and interlayer thickness requirements for different subgrade characteristics.

The CBR value, expressed as a percentage, is a comparative measure of the resistance offered by a soil to the penetration of a standard size cylindrical plunger, forced into the soil at a specified rate to a designated depth, to that resistance required to force the plunger into a standard crushed stone under the same conditions. The end area of the plunger is 3 square inches, the specified penetration rate is 0.05 inches per minute and the depth of penetration is either 0.1 or 0.2 inches. The test is conducted on the minus 3/4 inch fraction of a soil which is compacted by prescribed procedures into a 6 inch diameter mould. A 5 lb annular disk surcharge weight, which is intended to simulate the load of the pavement on the soil, is placed on the soil surface and the plunger is forced into the soil through the hole in the disk. The detailed procedure and apparatus used for conducting the test are described in the "Standard Test Method for Bearing Ratio of Laboratory-compacted Soils", ASTM Designation D1883-73.

The test may also be carried out on undisturbed soil samples taken in the field by the CBR mould, or on soaked or swelling samples. To minimize soil disturbance, the test can be conducted in the field on in-situ deposits by jacking the plunger into the ground, using for jack reaction the rear bumper or undercarriage of a truck, and measuring penetration by appropriately placed deformation gauges.

Design charts have been developed that relate pavement, base and sub-base thicknesses to vehicle wheel load and CBR values. A typical CBR chart is shown on Fig. 4-9. Use of the chart is illustrated by the following example.

A haulroad suitable for use by 170 ton GVW trucks is to be designed. As determined from exploratory drilling, ground conditions along the proposed road alignment consist predominantly of a deep deposit of firm to stiff lacustrine clay. Available construction materials include nearby deposits of clay till and limited terrace deposits of sand and gravel. In addition, copious quantities of mine spoil comprising approximately equal volumes of sandstone and mudstone are available at the minesite and crushed sandstone can be produced by the project crusher. Field and laboratory tests indicate that the CBR values for the various materials are as follows:

Material	CBR at Natural Moisture	CBR for Saturated Specimens
Crushed sandstone (compacted)	95%	95%
Pitrun sand & gravel (compacted)	68%	60%
Mine spoil (compacted)	49%	25%
Clay till (compacted)	53%	25%
Firm to stiff clay (in-situ)	15%	4%

Since the wheel load for a loaded truck is approximately 100,000 lb, the required thickness of better quality cover material to be placed over subgrade clay with a minimum CBR = 4% is 51 inches as determined from Fig. 4-9. Similarly, if mine spoil or till (CBR = 25%) is used as sub-base fill, the required depth of cover overlying the sub-base should be 15 in. By subtracting the two cover depths, the sub-base thickness is computed to be 36 in. A repeat of the procedure provides the thicknesses of base course and surface course as summarized in Table 4-5 and on Fig. 4-10. The vertical distance above the horizontal asymptote of the 100,000 lb wheel load curve represents the required thickness of surface course material.

Although the CBR values assumed in the above example are fictitious, they are not untypical and illustrate that substantial reductions in CBR can result when fine grained soils become saturated. It is considered prudent, therefore, to use the minimum CBR values when computing road fill thickness and accept the penalty of increased fill quantities as insurance against poor road performance should the fill and subgrade materials become saturated by rising groundwater levels, inclement weather or spring run-off.

The curves on Fig. 4-9 depict cover thickness requirements for a wide range of CBR values. The ranges of bearing ratios for the typical soils included at the bottom of the graph should be regarded as approximate and should be used for preliminary planning purposes only. For final design, CBR values obtained from field and laboratory testing of the actual subgrade and fill materials designated for road construction should be used in the CBR charts for determining fill thickness requirements.

Wheel loads for any hauler can readily be computed from the manufacturer's specifications. By dividing the loaded vehicle weight over each axle by the number of tires on that axle, the maximum load for any wheel of the vehicle can be established. In every case the highest wheel load should be used in the design computations. When a wheel is mounted on a tandem axle, the wheel load should be increased by 20% (KAUFMAN & AULT, 1977).

424 COMPACTION REQUIREMENTS

Once the depth of embankment fill and the thickness of the various sub-layers have been established for various subgrade conditions along the proposed haulroad route, proper placement procedures must be implemented. KAUFMAN & AULT correctly state that, regardless of the material used, the sub-base, base course and surface course should be compacted in layers not exceeding about 8 in in thickness.

To ensure stability of the final road surface, the embankment fill materials should exceed the final desired surface width by at least 2 ft and must always be compacted while moist. Compaction equipment should preferably consist of heavy (15 ton), smooth-faced, vibratory rollers for cohesionless materials or sheepsfoot rollers of a similar weight for cohesive soils. Since few mine operators include such equipment in their fleet, use can be made of loaded haulers or large dozers to compact the road fill. Compaction of each 8 in layer will require repeated passes (up to 6) of the compaction equipment until the soil no longer compresses under the weight of the vehicle. A more detailed description of a suitable construction procedure has been outlined by DIONNE (1987) based on haulroad construction practice at Syncrude Mine:

1. The proposed road alignment was proof-rolled with a loaded 170 ton Titan truck. Soft or weak areas were sub-excavated to competent ground and backfilled with suitable material placed in 20 cm thick lifts and compacted to 98% of Standard Proctor maximum dry density. This required about 6 coverages of the Titan truck. Generally, roads were constructed directly on top of the McMurray Formation containing the tarsand deposits.

2. After proof-rolling, the top 15 cm of the road bed sub-grade was scarified and re-compacted to 98% of Standard Proctor using a sheepsfoot or vibratory compactor.

3. The road sub-base has a maximum thickness of 1 metre and consists of granular material placed in 20 cm thick lifts compacted to 98% of Standard Proctor maximum dry density utilizing about 6 coverages of a vibratory compactor.

4. Road base course consists of a 0.5 m thick layer of well graded gravel placed in 15 cm lifts and compacted to 98% of Standard Proctor maximum dry density using a smooth drum vibratory roller. The surface or wearing course consists of a 0.3 metre thick layer of well graded crushed limestone placed in 15 cm lifts and compacted to 98% of Standard Proctor maximum dry density using the smooth drum vibratory roller.

5. The completed road surface was crowned 0.3 metres to facilitate drainage and sideslopes were constructed at 3H:IV.

6. Drainage ditches were installed on both sides of the haul-road to ensure good drainage.

7. Ramps were constructed with a maximum grade of 6%.

During road construction, progress was continuously monitored by Engineering personnel and a nuclear densometer was used to conduct in-situ density tests on each lift.

Rolling resistance tests were conducted on the native subgrade prior to road construction and subsequently on the competed road after one year of service. The respective values of rolling resistance were as follows:

Road Section	Length	Rolling Resistance Subgrade	 Road
Main Inpit Road	1000 m	7.0%	4.2%
NW Main Access Road	400 m	13.0%	3.4%
SW Main Haul	900 m	7.1%	3.9%

Due to a shortage of conventional aggregate reserves for road construction at the Syncrude Project, shortfalls were generally made up from the following sources (DIONNE, 1987):

- crushed siltstone from overburden spoil
- sand and gravel in other areas of leases
- tailings sand
- washed/crushed extraction rejects
- off-site limestone quarries

To determine the bearing capacity and trafficability characteristics of the Clearwater Formation, Syncrude embarked on a test pit and field testing program in 1983 prior to road construction. The Clearwater Formation, a layered marine deposit composed of varying amounts of clay, silt and sand, with clay being the predominate constituent, ranged in thickness from about 5 m in the east mine area to a maximum of 25 m in the west mine. The program consisted of excavating a 100,000 bcm test pit utilizing a Demag H241 shovel and 170 ton Titan haulers. The excavated material was used for haulroad construction tests and dump construction tests while the in-situ materials were subjected to pressure cell tests, plate loading tests, California Bearing Ratio tests and hauler rolling resistance tests. From the results of this program it was determined, among other things, that the Clearwater Formation could sustain a bearing pressure of up to 110 psi without excessive rutting and that the H241 Demag shovel exerted a maximum track pressure of 107 psi while digging. This demonstrated that large conventional shovels could be used in the Clearwater Formation provided the maximum bearing pressure was less than 110 psi (DIONNE, 1987).

425 SURFACE COURSE

After visiting over 300 mining operations in the United States, KAUFMAN & ~~Ault~~ AULT (1977) provide the following pertinent comments on haulroad surface materials:

> "At many of these mine sites, especially small coal mining and quarry operations, little consideration appeared to be given to the construction of a good haulage road surface. In fact, development of the haulageway is frequently accomplished by simply clearing a path over existing terrain.
>
> While this practice is undoubtedly the most economical means of road construction in terms of initial cost, the benefit is seldom long-lived. Failure to establish a good haulage road surface will result in increased vehicle and road maintenance costs and will severely retard the ability of a vehicle to safely negotiate the

> route. These difficulties are usually greatest on earth and bedded rock surfaces. Greater vehicle maintenance is required on rock surfaces as a result of excessive tire wear. It is virtually impossible to construct a bedded rock surface free of jagged edges. Thus, the tires of traversing vehicles are continually cut by scuffing.
>
> Earth roads, unless thoroughly compacted and stabilized, may cause both vehicular and road maintenance difficulties. Dust problems are frequent during dry seasons and, if not controlled, the dust can contaminate air filtration components, brakes, and other moving parts, making frequent replacement of these items necessary. Moreover, dust represents a major safety hazard to the vehicle operator in that it can become so dense that visibility is severely reduced. Eliminating the dust problem requires continual wetting of the surface, which represents yet another maintenance expenditure. When subjected to heavy wetting, nonstabilized earthen roads become extremely slick and severely defaced by erosion. Thus, rescued vehicular controllability from a slippery surface creates a safety hazard, and maintenance must be increased to eliminate erosion gullies. Jagged rock and unconsolidated earth surfaces should always be avoided in a safe haulage road design".

Besides compactness and durability, two additional properties are important in the design and construction of a haulroad surface - adhesion and rolling resistance. Road adhesion or friction coefficient between the road surface and the tire govern the potential for the vehicle to slide. Rolling resistance is defined as the combination of forces a vehicle must overcome to move on a specified surface. Generally an increase in road surface adhesion is accompanied by a corresponding decrease in rolling resistance.

Typical values of adhesion for various road surface materials are given in Table 4-6.

426 ROLLING RESISTANCE

An important measure of haulroad surface conditions is the rolling resistance, i.e., the amount of drawbar pull or tractive effort required to overcome the retarding effect between the hauler tires and the ground. Rolling resistance is composed of four main components (COLLINS et al, 1986):

- internal power train friction
- tire flexing under load
- tire penetration
- air resistance

The first two factors are approximately constant for a given hauler but may vary with tire wear, type of tire and inflation pressure. Tire penetration, on the other hand, depends primarily on the wheel load, number of tires in contact with the ground (single, dual, or tandem) and the condition of the road surface.

For a given wheel load and tire configuration, more tire penetration or rutting will occur in weaker soils than in stronger, well compacted soils forming the road surface. However, it is not necessary for tires to actually penetrate the surface for rolling resistance to increase. If the road flexes under load, the effect is nearly the same as the tire is always running "uphill". Recent studies by STUART & PETERSON (1989) indicate that, especially for roads on oilsand formations, large elasto-plastic deformations occur not only beneath the wheel but well beyond the plan outline of the truck, a phenomenon which would further contribute to rolling resistance.

An empirical expression for computing rolling resistance is as follows (CATERPILLAR, 1988):

$$RR = 2\% + 1.5\% \times \text{tire penetration (in)} \qquad \ldots.(6)$$

Where:

RR = Rolling Resistance, %

Model tests, conducted by measuring the towing force required to move a relatively lightly loaded wheel over a sand or clay surface, suggest, however, that equation (6) may significantly underestimate rolling resistance (see Table 4-7 and Fig. 4-11). The test data were quoted by KARAFIATH (1988) who also indicates that drive wheel slip is another factor which contributes to rolling resistance. Slip is especially significant when grade and rolling resistance are high or when the vehicle is being accelerated and wheel torque is 50% or more of the maximum torque. In off-road vehicle engineering, slip is defined as:

$$S = (V_p - V_t)/V_t \qquad \ldots.(7)$$

Where:

S = slip

V_p = peripheral velocity of tire

V_t = travel velocity of tire

The remaining factor which adds to rolling resistance is air resistance when the hauler is in motion. Caterpillar assumes an increase in rolling resistance of 0.025%/mph for vehicles travelling in the 0-40 mph range. This corresponds to an increase of (1% x GVW) in rolling resistance for a hauler travelling at 40 mph. It is evident from the foregoing statements that rolling resistance can be minimized by constructing and maintaining haulroads with a well compacted, smooth surface.

Rolling resistance for a given road and hauler type can be determined by pulling a loaded hauler with another vehicle such as a grader or truck and measuring the pull force required to move the hauler at a constant slow speed. The transmission of the loaded hauler should be in neutral during the test. Typical rolling resistance values for different road surface materials from a test carried out at Highvale Mine are given in Table 4-8. The equipment and procedure used in the test were as follows (MONENCO, 1983).

Equipment

1	Caterpillar 16G grader
1	Caterpillar 769C rear dump truck
1	set portable 400,000 lb truck scales
1	50,000 lb capacity dynamometer
1	level, rod and chain
2	wire rope slings

Procedure

- Weigh truck & record.

- Locate suitable site with slight uphill grade to ensure continuous dynamometer gauge reading. Record location and material description.

- Assemble slings and dynamometer on the ground in the necessary location. Position truck and grader such that dynamometer can be seen by the grader operator.

- Connect slings to truck and grader.

- Have truck operator put transmission in neutral.

- Signal grader operator to slowly tension the slings.

- Position gauge reader alongside dynamometer and signal grader operator to begin slow even pull of truck.

- Read dynamometer gauge upon attaining steady state motion and record reading.

- Using level, rod and chain, determine grade (slope) of ground travelled during the test and record.

- Move to next trial location and repeat procedure.

Although determining rolling resistance by using equipment normally employed at the minesite provides reliable values, such procedures are expensive and ties up equipment. An alternative approach is to use a lightweight trailer to conduct the test and correlate the results with tests using mine haulage equipment. Being less expensive to operate, the lightweight trailer could be used to accumulate additional data more frequently and hence provide a monitoring role to indicate signs of road deterioration.

KOLADA (1989) describes a specially constructed trailer that can be towed by a small truck and accurately measure rolling resistances using an on-board computer acquisition system. The main sensor used to determine rolling resistance consist of a load cell, an inclinometer and a velocity sensor. The load cell, installed in the trailer drawbar, records the drawbar pull. Both tension and compression forces can be measured. The cell is protected from twisting action by a linear bearing assembly and from overloading by a protective casing. The casing also prevents contamination by dust and water. The grade of the road is measured by a pendulum-type inclinometer attached to the drawbar behind the load cell. Excessive pendulum oscillations, which occur on rough roads but are not indicative of road grade, are automatically smoothed out by a data averaging process. Accurate ground speed measurements, used to compute forces due to acceleration and deceleration, are made with a radar gun similar to those used by police.

The relevant expression for determining the rolling resistance force is:

$$F = A + B + C \qquad \ldots.(8)$$

Where:

F = Force due to rolling resistance
A = Drawbar force
B = Extra force to travel uphill (negative if downhill)
C = Extra force required to accelerate (negative if decelerating)

Supplementary sensors include triaxial accelerometers to measure road surface roughness and wheel magnets to provide an indication of wheel slip and traction on soft, slippery roads.

4.3 HAULROAD TRAFFICABILITY

431 GENERAL

Poor haulroad trafficability and high vehicle rolling resistance are primarily caused by one or more of the following conditions:

- high groundwater levels within the road fill;

- excessive fines in the surface and base courses coupled with high moisture contents due to inadequate road crown and/or ditches;

- uniform rather than well graded material placed as surface and base course;

- insufficient depth or incompatible grading of road fill placed on soft, wet subgrade soils;

- bentonitic soils used as a surface course;

- insufficient percentage of fines to act as a binder in surface course.

432 DRAINAGE REQUIREMENTS

High groundwater levels in the subgrade and road fill give rise to diminished bearing capacity, excessive rutting, high rolling resistance and, in high embankments, instability of road side slopes. Seasonally fluctuating water levels can also result in uneven settlement of the road surface. In areas of naturally occurring high water table such as swamps or areas containing muskeg or water courses, good drainage must be effected to maintain low water levels in the road fill. This is usually accomplished by providing and maintaining adequate ditches along the road alignment, lateral ditches for swamp or muskeg drainage, culverting over stream courses and/or placing a sufficient depth of fill over the poor ground to ensure the stress increase due to traffic wheel loads is minimal at subgrade level.

Where permitted by local regulatory authorities, rock-fill causeways are sometimes used at water course crossings in lieu of culverts. In such cases coarse rock up to 1 m diameter is end-dumped from the advancing causeway, allowing the coarser fraction to accumulate at the base of the fill by segregation.

Haulroads constructed along mountain slopes may interrupt surface run-off channels or block natural springs emerging from the mountain side. To prevent high groundwater levels within the road embankment, free draining rockfill, clean sand and gravel or CMP culvert should be installed at the base of the fill. High water levels occurring in existing road fills can often be lowered by installing, at appropriate spacings along the downstream slope, perforated horizontal drain pipe or backhoe excavated finger drains backfilled with gravel.

Trafficability on temporary in pit roads with high groundwater levels can be improved by placing a gravel or rockfill pad over the offending area or by installing pumping wells to lower the water table if a pumpable aquifer exists at depth. The latter procedure may be cost effective if it also reduces the water level in, and improves the stability of, the shovel working face.

At the Leigh Creek mine in South Australia, piezometeric heads up to 2 m above the shovel bench were sufficient to shut the job down until the trafficability problem was resolved. The problematic formation was a very poorly indurated, silty fine sandstone forming the footwall which dipped about 30 degrees into the highwall. Upon exposure, the deposit appeared dry due to high evaporation losses but would not support loaded haulers which bogged down on the first pass. The problem was overcome when a pumpable aquifer was discovered by exploratory drilling of a test area and pumps were installed to depressurize the aquifer. Periodic moisture content determinations of the silty sandstone and trial runs with a Terex hauler while pumping was in progress indicated that a head drawdown of 4 m was sufficient to reduce the moisture content within the top metre of the formation and thus obtain satisfactory trafficability. To better assess the trafficability characteristics of the same formation elsewhere in the mine, an empirical relationship was developed (CONNELL MONENCO, 1987) wherein the ratio of the truck weight times the number of passes to the measured rut depth caused by the tires was correlated with formation water content as shown on Fig. 4-12. The maximum tolerable water content for adequate trafficability was designated to be that water content at which the limiting curves become asymptotic to the x-axis, or on average about 7.5%.

433 WEARING SURFACE

The most practical construction materials for developing a haulage road surface that will ensure maximum safety and operational efficiency are: rollcrete, asphaltic concrete, crushed stone or gravel and stabilized earth. The advantages and disadvantages of each material are discussed in the following paragraphs and summarized on Table 4-9.

Rollcrete

Roller-compacted concrete, or rollcrete, consists of premixed concrete which is dumped on the roadbed, spread to a uniform thickness with a dozer or grader and compacted with a vibratory roller in the same manner utilized to compact rock fill. Although lift thicknesses for mass rollcrete can vary to 60 cm, road surface applications should be limited to individual lifts not exceeding about 30 cm. Water : cement ratios should be adjusted to produce a stiff, zero slump mix with 28-day uniaxial compressive strengths from 15 to 30 MPa. Compared with conventionally formed concrete, the inplace cost of rollcrete is appreciably less (40% to 60%) as a result of placement efficiencies, high placement rates and the absence of labour-intensive formwork.

According to American Concrete Institute (ACI, 1988), rollcrete must be placed in layers or lifts thin enough to allow complete compaction by the vibratory roller or plate compactor. To date field tests have indicated that optimum placement layers range from 20 to 30 cm. This contrasts to normal layers in conventional mass concrete of 46 to 60 cm. Considering the high placement rates attainable, several pieces of dumping and spreading equipment may be necessary to keep pace with one large vibratory roller. A 1.5 m wide vibratory roller making four passes travelling at a speed of 3.25 km/hr can compact more than 260 cu.m per hour of zero-slump concrete in 25 cm layers. Generally any vibratory roller which has been successfully used to compact rockfill will compact rollcrete. Self-propelled rollers with power driven vibrating drums have proven more suitable for rollcrete than towed vibratory rollers.

An example of placement rates achievable is indicated in the following case history at an earth dam site. In early 1975, approximately 344,000 cu.m of rollcrete was placed in Tarbela Dam, Pakistan, to replace rock and embankment sections washed away when one tunnel of the outlet works collapsed during first filling of the reservoir. The rollcrete was placed in 44 days averaging in excess of 7,600 cu.m daily, with a maximum daily placement of 19,000 cu.m. This placement method offered the only suitable method of repair which could be successfully accomplished in the restricted time period before the start of the rainy season and filling of the reservoir (CHAO & JOHNSON, 1979).

Rollcrete produces a tough, hard, durable surface that, when properly smoothed by mechanical screeding and trowelling, will exhibit a long-lasting smooth profile with low rolling resistance and high traction characteristics (see Tables 4-6 and 4-8). Prior to placing the rollcrete, a sufficient thickness of compacted sub-base must be established, followed by an additional layer of compacted base course to form the foundation for the rollcrete surfacing. No established procedure is available to determine the minimum thickness of rollcrete on heavily loaded haulroads. One approach would be to construct a trial rollcrete pad with varying thickness in a section of an existing road and monitor its behaviour for a couple of years. A similar procedure was adopted in 1988 at the Syncrude minesite when a trial pad 400 m long x 25 m wide was constructed with a uniform thickness of 0.6 m. Although the thickness was arbitrarily chosen, 60% of the length was spread with a mechanized paver while a dozer was used for the remainder. After spreading, the rollcrete was compacted with a vibratory, smooth-faced, drum roller. The concrete mix consisted of minus 1.5 in crushed aggregate with 8% cement content by weight. No performance data on the test pad were available at time of writing. The estimated cost of the 0.6 m thick rollcrete surface was approximately $1 million per mile.

Asphaltic Concrete

Like rollcrete, asphaltic concrete exhibits a high coefficient of road adhesion and creates a surface that minimizes dust problems. In addition, the characteristic stability of this material creates a smooth haulage surface that can be travelled with little fear of encountering rut or potholes that would impede hauler controllability. Should potholes or ruts occur, they can readily be corrected by patching. KAUFMAN & AULT (1977) state that:

> "These surfaces are equally attractive from a production standpoint. While an increasing number of operators are beginning to utilize asphaltic concrete because of lower road maintenance costs, the smooth surface also allows haulage vehicles to travel safely at greater speeds. This speeds up the production cycle.

> A seasonal disadvantage to using this composition, however, is revealed during the first snow or freezing rain. The characteristically smooth surface of asphalt offers little resistance to development of an ice or snow glaze. Thus, the roadway can become extremely slick and remain so until corrective measures are employed. This could constitute a serious threat to operational safety in mining areas where rapid and frequent freeze conditions prevail."

Being an engineered material, asphaltic concrete must be processed and applied within the constraints of good engineering practice. In order to be stable, the exact mix of aggregate and asphalt cement suitable for locally available materials should be obtained from provincial Highway Departments, ~~pairing~~ paving contractors or consulting engineers experienced in pavement design. As with roll-crete construction, asphaltic concrete must be placed on an adequate thickness of well compacted sub-base and base course material. ~~It is recommended that the base course material~~. It is recommended that the base course consist of crushed rock with a CBR of 90% or more. KAUFMAN & AULT (1977) indicate that, due to the high wheel loads imposed on the haulroad surface, a 4-inch layer of asphaltic concrete should be considered the minimum thickness for a surface course. More recently, SHUKLA et al (1989), in their studies on haulroads in India, have developed tentative empirical criteria for pavement thickness based on an equivalent wheel load derived from considerations of the pavement deflections under single and multiple-configuration wheel loads, respectively. Using these criteria, the authors determined the total roadfill thickness for various haulers and equivalent wheel loads (see Table 4-10). For a base course having CBR = 80% or more, the thickness of asphaltic concrete to withstand one million wheel load applications should be:

Hauler Capacity (tonnes)	Asphaltic Concrete Thickness (cm)	
	Loaded Truck	Unloaded Truck
120	27.5	17.5
170	32.5	17.5

SHUKLA et al (1989) computed the relative costs of conventional haulroads with granular construction vis-a-vis haulroads with bituminous surfaces by making the following assumptions:

- Bituminous roads require resurfacing every five years whereas granular construction requires a renewal coat every 6 months;
- Hauler fuel consumption on granular roads is 1.5 times higher than on bituminous roads;
- Tire life on bituminous roads is double that on granular roads;
- Vehicle depreciation is less on bituminous roads.

Based on the above assumptions, the authors estimated that, although the initial cost of bituminous roads is approximately 70% higher than granular roads, the cummulative discounted vehicle operation cost per 100 trucks on bituminous roads over a 20 year period is about 84% of the equivalent cost on granular roads. Because of resurfacing every five years, the maintenance cost for bituminous roads is about 6% higher than that for granular roads.

The estimated net savings amounted to the equivalent of $40 million.

The authors conclude that bituminous pavements:

- can be designed and constructed by the same procedures used for less heavily loaded highways provided the heavier wheel loads on haulroads are taken into account;
- provide low rolling resistance and dust free service;
- show cost savings when the cost of construction and maintenance are compared with cost of grading unpaved roads, fleet maintenance costs, tire costs, fuel costs, etc.

Because of the relatively high cost of asphaltic concrete surfaces, each mine operator must assess if the benefits of increased speed and reduced road maintenance will offset the high initial cost. The determining factors will generally be the length of haul and the required haulroad life. If the road life is relatively short, an asphalt surface may be difficult to justify. On the other hand, if the haulroad is long and is to be in service for a number of years, placement of asphaltic concrete may prove feasible (KAUFMAN & AULT, 1977).

Compacted Gravel and Crushed Stone

Because gravel or crushed rock, when locally available, can be used to construct a safe and efficient roadway rapidly and at relatively low cost, one or the other is often the preferred material for haulroad surfacing at many minesites. When constructed and maintained adequately, both materials offer a stable roadway that resists ~~in~~deformation and provides good traction with low rolling resistance. The required thickness of surfacing material, as well as the associated sub-base and base course materials, can be determined from the CBR curves (Fig. 4-9). A satisfactory gradation for granular surface materials is provided in Table 4-11. However, roads subject to freezing or prolonged inclement weather should not contain more than 10% fines (less than No. 200 U.S. Standard sieve size) to prevent muddy, slippery conditions when wet or thawing. Those subject to hot, dry weather should contain at least 5% fines to minimize dust problems and surface loosening when dry. Granular surfacing should be free from loam, roots, vegetation matter, frozen lumps and other unsuitable material. The particles of the granular material should be clean, sound and durable. When gravel is used, 30% or more of the particles larger than 3/8 inch should have fractured faces. Granular surfacing material should be placed in layers not exceeding 200 mm in thickness prior to compaction. Each layer should be uniform in gradation and moisture content, spread without causing particle segregation and compacted with a vibratory smooth drum roller weighing at least 15 tonnes to at least 98% of Standard Proctor maximum dry density as determined in the laboratory. Where haulroads are to be used by 170 ton capacity or larger haulers, each layer of surface course should be compacted to a dry density of at least 98% of Modified Proctor maximum dry density.

Other suitable materials which can be used in lieu of gravel or crushed rock include fine shot rock, scoria (vesicular lava), slag, cinders, volcanic ash, mill tailings and disintegrated granite or shale. Note that those materials which contain more than the recommended fines content may necessitate increased road maintenance. In addition, volcanic ash, if altered by weathering, may be bentonic which would cause slippery conditions when wet.

Stabilized Earth

Any soil that has been transformed from its natural state by special procedures or additives is known as stabilized earth. Within the haulroad context, this generally means increasing the soil strength and bearing capacity by incorporating cementing agents such as Portland cement, asphalt, fly ash, calcium chloride, lignosulfates or hydrated lime. Such treatment, however, will not generally improve native soils to the extent that they can be used as surfacing materials, but when applied to subgrade, sub-base or base course materials can often substantially reduce the quantity of road fill beneath the surface course. An exception is fly ash exhibiting pozzolanic or self-cementing properties which has been used on a trial basis at Highvale Mine. The fly ash was mixed in place on the road surface with poorly indurated sandstone spoil and gravel and subsequently compacted with loaded haulers. Performance of the stabilized surface has been very good.

4.4 SUBGRADE STABILIZATION MEASURES

441 GENERAL

Most mine haulroad designers have been confronted at one time or another with poor subgrade conditions such as swamps, muskey, loose mine spoil, old lake deposits, etc. and the methods used to stabilize them have been varied and sometimes unique. The civil engineer, in his efforts to provide good foundations for roads, buildings, railroad embankments, earthdams and other projects, has also devised numerous methods of ground stabilization which may be applicable to minesite conditions as well. Examples of different soil improvement methods that have been used are summarized on Table 4-12. CARTIER et al (1981) illustrate ways in which old tires may be arranged and interconnected to form tensile reinforcements for subgrades and embankments.

442 GEOTEXTILES

Geotextiles are often used as an economic method of improving the strength and bearing capacity of man-made fills and embankments. Construction of roads and airport runways over weak, saturated cohesive soils, muskeg, or marshy areas can often be accomplished by installing a geotextile on the surface of the poor ground prior to fill placement to effect basal reinforcement and reduce settlement and lateral spreading of the fill. Numerous successful applications of this method on conventional highways have been reported (DIYALJEE and COMCHI (1985), PRICE (1985)).

Geotextiles are generally considered suitable for use in haulroads travelled by low to intermediate weight haulers up to and including Vehicle Weight Category 2 (maximum GVW - 200,000 lb). Typical design guidelines for road construction utilizing geotextiles to improve the bearing capacity of low strength subgrades and provide separation between the subgrade and the roadfill are outlined in Appendix C for Exxon products. Similar guidelines are generally available from most geotextile manufacturers. A partial listing of geotextile suppliers is as follows:

Manufacturer/Supplier	Sample Product
Burlington Industries	Bi-tech 3013
Crown Zellerbach	Fibrex 400
DuPont	Typar 3401
Hoechst	Trevira Spunbound S1155
Mirafi	600X
Phillip	Supac 8NP
Tensor	SS1
Penroad	P50

For haulers with GVW exceeding about 150,000 lb, the tensile stress developed under the heavy wheel loads exceed the tensile strength of most geotextiles currently available and hence geotextiles should not be used in haulroads travelled by vehicles heavier than Vehicle Weight Category 2.

443 GEOGRIDS

The Tensar geogrid, produced by Tensar Corporation, a firm jointly owned by Gulf Canada and Netlon Ltd. of England, is a lightweight mesh composed of high tensile polymer plastic which is used for structural reinforcement in weak soils. Analogous to steel reinforcing mesh in concrete, the geogrid is installed in road embankments, foundation backfills or over marsh areas prior to fill placement to strengthen the soil mass and reduce excessive displacements. The Tensar geogrid has approximately the same strength as mild steel but, as a polymer material, possesses several beneficial characteristics not found in steel as it:

- will not rust and is lightweight
- has low creep properties
- has good thermal stability
- exhibits high chemical resistance to acidic and alkaline soils
- offers good biological resistance to bacteria and fungi
- is electrically non-conductive and non-magnetic

The polymer grid has a tensile strength ten times that of a typical geotextile and will readily withstand the rigors of heavy traffic.

Use of geogrids in roads and oil rig working pads constructed over muskeg has reportedly reduced fill requirements by approximately 35% and shortened construction time by 25%. Peak geogrid installation and overfill cover rates have reached 25,000 sq. m per day on one oilfield highway project in northern British Columbia.

No special equipment is required for installation of geogrids. It is delivered in rolls weighing from 67 to 135 lb depending on strength, is easily handled by two men and is installed by unrolling over the ground or fill to be reinforced. Typical geogrid specifications are given in Table 4-13.

When used for fill base reinforcement, the following installation guidelines are suggested (TENSAR, 1987):

Step 1 - Site Preparation

- Clear and grub site of all topsoil, trees, stumps, rocks and other debris. For construction over peat, muskeg or marshland, it is sufficient to cut and lay flat all brush and trees, leaving roots and vegetative cover in place.

- After clearing, grade and proof roll the subgrade allowing sufficient cross slopes for adequate drainage. For soft saturated soils and deep organic soils, place grid directly over unprepared surface. To prevent pumping through the geogrid during subsequent construction, it may be desirable to place a nonwoven geotextile under the geogrid.

Step 2 - Placing and Overlapping Geogrids

- Place geogrid in position and unroll over the prepared subgrade. Geogrid should be cut as necessary to conform to manholes or other protrusions, or cut and overlapped to accommodate curves in road alignment. Pin overlaps to prevent separation and provide anchorage.

- If two unrolled strips are to be placed side by side or end to end, overlap as follows:

Soil Type	CBR	Overlap
Firm	2+	1 ft
Soft ground	1-2	2 ft
Very soft ground	0-1	3 ft

- Overlap geogrids in the direction of fill placement. On very soft ground overlaps should be secured as necessary with wire, plastic ties or hog rings at five to twenty foot spacings.

Step 3 - Tensioning and Pinning

- On firm ground, pin beginning of roll to the ground and pull tight by hand to take up slack then anchor geogrid to ground at edges, overlaps and in centre of strip at 30 ft intervals along the length with 6 in "U" staples or other approved fasteners.

- On soft ground, anchor only the terminal ends and overlaps of the geogrid strip. The geogrids will conform to the ground surface as the fill is placed.

Step 4 - Dumping and Spreading

- On firm ground, good anchorage is required to prevent haul traffic from pushing or shifting the grid out of position. Back dumping can be employed, otherwise rubber tired end dump trucks or belly dumps can drive over the grid at speeds no more than 5 mph dumping as they go. Haulers should avoid turns and sudden stops. Tracked vehicles should not be driven directly on the geogrid until it is covered with a minimum of 4 in of fill. Grade fill to the required thickness with a dozer, raising the blade while spreading. Crown levelled fill to ensure rainfall runoff and prevent saturation.

- On soft ground, all fill should be placed by backdumping. Dump fill onto the geogrid where subgrade is most stable and spread the fill material over the grid in the direction of the softer ground. Low ground pressure dozers and trucks with low tire pressures (less than 4 psi) are recommended for the spreading and hauling fleet. Grade fill to the specified thickness raising the dozer blade gradually as the fill is pushed out over the grid. This causes the fill to roll out onto the grid and reduces stresses on the subgrade. Backdump subsequent loads on the levelled fill and advance forward by spreading with the dozer.

Step 5 - Compaction

- Compact fill to the required specifications after it is graded smooth and before it is open to truck traffic. Inadequate compaction will result in surface rutting under wheel and track loads. For very soft subgrades, use a smooth drum roller rather than a vibratory compactor to avoid inducing a "quick" condition and rapid loss of strength in the subgrade.

Additional Suggestions and Guidelines

Repairs to Geogrid

Damage to the geogrid during or after installation can be repaired by patching. Remove any fill from the surface of the grid at, and 3 ft around, the damaged area. Cut a patch of geogrid large enough to cover the damaged area plus an extra 3 ft all around, and cover the damaged area. Then replace fill and compact.

Recommended Type of Fill

For base reinforcement applications, the preferred cover-fill is a well-graded crushed rock with the following gradation:

Size	% Finer
1.5"	100
0.75"	50 - 100
#4	25 - 50
#40	10 - 20
#100	5 - 15
#200	Less than 10

Uniformly graded silts, sands or gravels should not be used as overfill since they are difficult to compact and will rut under wheel loads despite improved stability brought abut by geogrid base reinforcement. In addition, placement moisture content of the fill should not exceed the laboratory-determined optimum moisture content as fill with excessive moisture will not compact well and will rut easily under wheel loads. Rut formation is an indication that the fill layer is too wet, inadequately compacted or too thin. Remedial measures to eliminate rutting consist of backfilling with specified granular fill placed in layers and compacted or, in areas of deep rut formation, carefully removing the rutted materials and backfilling as above.

Fill Thickness Requirements

The minimum thickness of fill to be placed over the geogrid to provide a satisfactory road surface depends on:

- the wheel loading
- the strength of the subgrade
- the strength of the fill itself

Guidelines for computing the thickness of geogrid cover-fill as provided by the manufacturers are as follows (TENSAR, 1988):

- Preamble.

"This Design Guideline outlines a procedure for designing TENSAR Geogrid reinforced borrow or graded fills over soft subgrade soils. Required thicknesses of both reinforced and unreinforced fills necessary to support dynamic construction loads can be determined for any combination of subgrade strength, fill types and dynamic loading. The function of the reinforced fill is to distribute the surface loads and reduce stresses on these subgrade to a level that does not exceed the bearing capacity of the soil in local shear failure"

- Disclaimer by TENSAR

"The information herein has been carefully compiled by The Tensar Corporation and to the best of our knowledge accurately represents Tensar products use in the various applications which are illustrated. Final determination of the suitability of any information or material for the use contemplated, and its manner of use, is the sole responsibility of the user".

- Basis for Guidelines

"A subgrade soil can fail under load in two ways: localized shear failure and deeper seated bearing capacity failure. Localized shear failure or base punching typically occurs in the form of severe deformation or rutting in soft saturated subgrades when loading exceeds the subgrade shear strength. The subgrade beneath an unreinforced fill will fail in localized shear failure at about half the stress level than the ultimate bearing capacity of the subgrade".

TENSAR Geogrid reinforcement of fills over soft ground can prevent localized shear failure of the subgrade and therefore significantly increase the bearing capacity of the subgrade. In addition, TENSAR Geogrid reinforces the granular fill through confinement stiffening the base layer for improved load distribution. The combined effect of preventing localized shear failure and stiffening allows for placement and compaction of granular base layers over relatively unstable subgrade conditions. The net effect is a reduction in fill thickness to provide a stable subgrade.

The increase in the bearing capacity factor made possible by the use of TENSAR Geogrids, allows for a 30 to 50% reduction in the required fill thickness depending on the subgrade bearing capacity.

Depending upon the type of fill that is used it will also be necessary to check the bearing capacity of the compacted fill with respect to construction loads in order to determine if a better quality material is required for the upper portion of the total required thickness".

- Design Parameters

"The following variables are required for the design of TENSAR Geogrid reinforced earth fills:

Input Parameters

c_u - undrained shear strength of subgrade soil (may be derived from vane shear test, cone penetrometer test or correlated from CBR value), psi (See Table 4-14).

c_f - shear strength of fill material, psi (See Table 4-14).

P - dynamic load imposed by single, dual or tandem wheel or single track of a tracked vehicle, lb.

p - tire inflation pressure (single or dual wheels) or surface contact pressure under load P (tandem wheel or track), psi

N - bearing capacity factor, dimensionless

N_u - 3.1 (Unreinforced Fill)
N_r - 6.2 (Fill Reinforced with TENSAR Geogrids)

a - axle spacing (tandem axles), in.

b - total width of dual wheels (tandem axles), in.

B - width of track, in.

Calculated Parameters

R - apparent radius of loaded area, in.

q_u, q_r - allowable bearing pressure on subgrade, unreinforced and reinforced respectively (equivalent to apparent bearing capacity), psi.

z_u, z_r - required fill or aggregate thickness to support dynamic loads, unreinforced and reinforced respectively, in.

- Design Guidelines

Step 1

Determine the undrained shear strength, c_u, of the subgrade (i.e. field vane shear test under saturated conditions, unconsolidated undrained triaxial test or correlation to some other test value such as CBR, standard penetration test, cone penetrometer, etc. (See Table 4-14).

If the design wheel loads are the same as or similar to the following wheel loads, proceed to the appropriate ~~f~~Figure to determine required thickness, unreinforced versus reinforced. ×

Wheel Load, lb	Type	Figure
9,000	Dual	4-13
12,000	Dual	4-14
32,000	Single	4-15
60,400	Single	4-16
46,000	Dual	4-17
100,000	Dual	4-18

Step 2

For cohesive subgrade soils calculate the allowable bearing pressure, q, on top of the subgrade corresponding to the bearing capacity for unreinforced and reinforced fills:

$$q_u = N_u c_u \qquad \text{....(9a)}$$

$$q_r = N_{\cancel{u}\,r} c_u \qquad \text{....(9b)}$$ ×

Where:

$N_u = 3.1$ (Unreinforced)

$N_r = 6.2$ (Reinforced)

For cohesionless subgrade, determine the angle of internal friction by appropriate field or laboratory tests and compute the bearing capacity, q, as follows:

Unreinforced

$$q_u = 1/2\gamma_1 B_1 N_\gamma + \gamma_2 D N_q \qquad \text{....(10a)}$$

Where:

B - Width or Diameter of Loaded Area
γ_1 - Unit weight of subgrade soil
γ_2 - Unit weight of fill
D - Depth of fill
phi - Angle of internal friction of subgrade soil
N_γ, N_q - Bearing Capacity factors for local shear

The Meyerhof bearing capacity factors for sensitive-local failure in sands are as follows:

phi	N_γ	N_q
15	1.0	2.6
20	1.0	3.3
25	2.0	4.8
30	3.9	7.0
35	7.5	10.2

Reinforced

$$q_r = 2.0 \times q_u \qquad \text{....(10b)}$$

Step 3

Determine the design load, P, the contact pressure and contact dimension. For rubber tired vehicles, the design load is the wheel load (1/2 axle load). The contact pressure is assumed to be the same as the tire inflation pressure.

For single and dual wheels the contact dimension is defined by the apparent radius of contact, R, using the equation:

$$R = (P/3.14p)^{0.5} \qquad \text{....(11)}$$

For tandem axle loads the contact area is a x b. The contact pressure, p, is defined as P/(a x b) and the apparent radius of contact is determined using Equation ~~10~~ 11.

For track loads, the contact pressure is equal to one-half the weight of the machine divided by the area of one track in contact with the ground.

Step 4

Calculate the thickness of unreinforced fill, z_u, required to prevent bearing failure of the subgrade soil.

Wheel Loads

$$z_u = R/[(1/(1 - q_u/p)^{0.67}) - 1]^{0.5} \qquad \text{....(12a)}$$

Where:

q_u = allowable bearing pressure on subgrade (unreinforced case) where localized shear failure controls.

Track Loads

Determine the allowable bearing pressure q_u, q_r, as a decimal fraction of the surface contact pressure, p.

$$\text{Unreinforced } F_u = q_u/p \qquad \text{....(13a)}$$

$$\text{Reinforced } F_r = q_r/p \qquad \text{....(13b)}$$

Refer to Fig. 4-19 to determine the required thickness of unreinforced fill as a multiple, M_u, of the track width, B. Determine the required thickness of fill.

$$\text{Thickness of fill, } z_u = M_u \times B \qquad \text{....(14a)}$$

Step 5

Wheel Loads

Repeat step 4 to determine the required thickness of reinforced fill, z_r, substituting the allowable bearing pressure, q_r, for the reinforced case into the equation:

$$z_r = R/[(1/(1-q_r/p)^{0.67}) - 1]^{0.5} \qquad \text{....(12b)}$$

Track Loads

Repeat Step 4 to determine the required thickness of reinforced fill, Z_r, using F_r and q_r to determine M_r from Fig. 4-19 and substituting into the equation:

$$z_r = M_r \times B \qquad \text{....(14b)}$$

Step 6

Check the bearing strength of the fill, $q_f = 3.1\ c_f$, to determine if it is capable of supporting the construction loads (c_f = shear strength of cohesive fill). The shear strength of the fill can be determined by any of the test methods outlined in Step 1 or can be estimated using typical Soil Classification charts such as the one shown in Table 4-15 and the correlated value give in Table 4-14.

Repeat Steps 1 through 4 substituting the shear strength of the fill, c_f, rather than the subgrade, into Equation 9.

For cohesionless fill, determine the angle of internal friction for the placement density specified and compute the bearing capacity of the fill from Equation 10.

If the actual bearing pressure on the surface of the fill is greater than the fill bearing strength, it will be necessary to use a higher bearing capacity material for the upper portion of the fill. If the bearing strength, q_u, is satisfactory, go to Step 10.

Select a higher bearing capacity material (e.g. aggregate) to place on top of the initial fill material as part of the required total design thickness. As a rule of thumb, the material should have a CBR value greater than the contact pressure divided by 10, ($CBR>p/10$), in order to resist shear failure due to the design leads. The Soil Classification chart of Table 4-15 can be used to estimate the CBR of a given material.

Step 7

Determine the required thickness of the higher bearing capacity material in order to prevent bearing failure of the underlying fill.

Step 8

Subtract the required thickness of the higher bearing capacity material determined in Step 7, from the total required thicknesses determined in Steps 4 and 5 to determine the required thicknesses of unreinforced and reinforced fills respectively. The required thickness of surface material remains the same for both cases unless a second layer of TENSAR Geogrids is considered at the fill-aggregate interface to reduce aggregate thickness requirements.

Step 9

Determine the maximum allowable construction loads over each intermediate fill lift and/or over the surface of the fill prior to placement of the top life of surface material, using the equations:

$$P_a = q/\{1-[1/(1+(R/z)^2)]^{3/2}\} \text{ and} \qquad \text{....(15a)}$$

$$P_a = p_a \times 3.14 \times R^2 \qquad \text{....(15b)}$$

Step 10

Compare costs of the reinforced and unreinforced designs. Use in-place material costs.

A worked out design example using Tensar geogrids is given in Appendix D.

444 GEOCELLS

A novel method of embankment construction over soft, compressible soils, consisting of a mattress of high strength geogrids assembled as a cellular structure and backfilled with free draining granular materials, has been successfully implemented in Scotland (GILCHRIST, 1988). The mattress was constructed in-situ as per the following procedure:

- Trees and shrubs were removed to gain access to the site. Stripping of the organic topsoil as not considered necessary.

- Strips of geogrid, typically 4 m wide, were unrolled over the poor ground parallel to the road alignment, with adjacent strips lapped by about 0.5 m. These strips formed the base of the mattress.

- Next, 1 m wide geogrid strips were installed on edge vertically at 1 m spacing to form the main diaphram walls running parallel to the road centreline. The diaphram walls were stitched to the base material using HDPE braid.

- After tensioning the main diaphrams, secondary diaphram walls, also consisting of 1 m strips, were then attached to the main diaphrams with steel bodkins to form equilateral triangular cells with 1 m long sides. Over areas where edge stiffening was deemed necessary, 0.5 m triangular cells were constructed using short intermediate transverse diaphrams.

- The assembled cellular mattress skeleton was then infilled with free draining materials, ensuring that no cell was filled to more than half the height of the adjacent cells to prevent excessive bulging of cell walls. Cell infilling was performed with a backhoe, although a shovel or gradall should work equally well.

- The cell backfill was not compacted and slight overfilling compensated for minor settlements and also protected the top of the diaphram walls from damage.

- As cell backfilling progressed, the filled cells were used as a platform to support the infilling equipment and the delivery of infill materials. At no time did the Contractor's equipment operate on soft ground and thus delays from bogging down were eliminated. In addition, it was possible to carry out the backfilling operation during inclement weather without incurring delays.

- When construction of the mattress was complete, placement of the road fill directly on the mattress commenced. The geogrid materials used for the mattress base and diaphram walls were Tensar SS2 and SR2 types, respectively (GILCHRIST, 1988).

As a structural component, the geogrid mattress was assumed to exhibit the following characteristics:

- sufficient tensile strength to ensure the full undrained shear strength of the subgrade is mobilized along the mattress base;
- sufficient rigidity to maintain a uniform pressure distribution on the soft subgrade soils. Rigidity is provided by the high tensile strength of the diaphram walls and the triangular shape of individual cells;
- high frictional contact with the underlying subgrade. This is a result of partial penetration of the granular infill through the apertures of the basal geogrid.

The project reported by GILCHRIST consisted of a 4.2 m high highway embankment containing the 1 m high geogrid mattress or Geocell, which was constructed over a 4 m thick marsh deposit of peat, loose organic clayey silts and very soft, varved silty clay. The marsh deposits were resting on a relatively competent weathered mudstone and the groundwater level was located just above the mudstone surface. The average undrained strength of the in-situ marsh deposits was 15 kPa.

GILCHRIST reports that, over the 200 m long section of road containing the geocell foundation, no differential settlement was observed and the uniform settlement at the end of geocell construction was about 90 mm prior to placement of the conventional road fill. The installed cost of the geocell mattress was approximately $45/sq m in 1986.

4.5 DUST SUPPRESSANTS

Field trials to evaluate the effectiveness of various dust suppressants were conducted over a two month period in the summer of 1986 on a segment of haulroad at Highvale Mine (MONENCO, 1986). The site consisted of seven 300 m long x 25 m wide contiguous test sections which included two untreated control sections, one water test section and a single section for each of the following dust control chemicals - emulsified asphalt, calcium chloride, calcium lignosulfonate and a surfactant. The chemicals were applied to the road surface using rates and procedures recommended by supplier and literature sources. In the water test section, water was applied through a sprinkler bar attached to the mine water truck generally used for this purpose.

The characteristics of the chemical products used are as follows:

- emulsified asphalt - contains an emulsifying agent, water and asphalt, and cures by by evaporation of water from the mixture. A product called DL-10 asphalt emulsion, manufactured by Pounder Emulsions, was used for this application. DL-10 is designed to remain flexible after curing allowing for road maintenance without loss of dust control effectiveness.

- calcium chloride - a hygroscopic compound that extracts moisture from the atmosphere and dampens the road surface. The product used for this program was a natural salt brine with a minimum calcium chloride content of 26% supplied by Tiger Chemicals Ltd.

- calcium lignosulfonate - an organic by-product of the sulphite wood-pulping process which can be used to physically bind soil particles together. It was supplied by Mackenzie and Feimann Limited under the trade name M&F Road Stabilizer.

- surfactant - substances capable of reducing the surface tension of the transport liquid, thereby allowing available moisture to wet more dirt particles per unit volume. Alchem Inc. supplied a surfactant called Alchem 8808 for this application.

The procedures used for applying the various palliatives are summarized below:

DL-10 Asphalt Emulsion - (one application)

- the road surface was scarified to a depth of approximately 50 mm using the shanks on a road grader;

- the scarified material was placed in windows on the haul road shoulder;

- about one-half of the emulsion was applied; and

- the windrows were graded over the road surface and the remainder of the emulsion was applied.

Calcium Chloride - (two applications ten days apart)

First application

- the upper 13 to 25 mm of the road surface was graded off and placed in windrows on the road shoulder;

- one-half of the calcium chloride solution was applied; and
- the windrows were bladed over the road surface before applying the remainder of the calcium chloride solution.

Second Application

- the road surface was scarified to a depth of 150 mm and the loose material was placed in five windrows evenly spaced across the roadway;
- approximately one-half of the solution was applied between the windrows; and
- the windrows were levelled and the balance of the solution was applied.

Calcium Lignosulfonate - (one application)

The calcium lignosulfonate was applied using the procedures noted above for the initial calcium chloride application. The material was applied at a rate of 1.5 litres of concentrated lignosulfonate per square meter. The concentrate was cut 50/50 with water so that the dilute solution was applied at a rate of 3.0 L/m^2.

Surfactant - (nine applications 2 to 4 days apart)

The surfactant (Alchem 8808) was unlike the other chemical palliatives in that no special road preparation was required. The material was supplied in 22 L pails which were manually emptied into the inlet at the top of the water truck as the tank was filled with water. The first five applications were at a surfactant concentration ~~were at a concentration~~ of ~~1~~ 2% of the applied water volume whereas subsequent applications were at a concentration of 1%. ×

The emulsified asphalt, calcium chloride and calcium lignosulfonate solutions were applied using tanker trucks equipped with solution pumps and rear spray bars. The surfactant solution ~~were~~ was applied by the water trucks normally used for haul road dust control. The calcium chloride and calcium lignosulfonate solutions were applied by their respective suppliers while the other palliatives were applied by minesite personnel. At the time of the initial chemical applications in mid-June, the haul road was in good condition with a well compacted surface generally free of ruts, depression and potholes. The quantity of the different suppressants applied during each application and the approximate prorated cost per kilometre are summarized in Table 4-16.

Effectiveness of the various dust suppressants was monitored in two ways:

- visual evaluation and assignment of a rating between 0 (worst dust conditions) and 5 (best conditions), and

- total and fixed dustfall analyses of samples collected from two dustfall stations located at the midpoint of each test section.

Total dustfall is defined as the amount of material left after evaporation of a dustfall sample and its subsequent drying. It includes both suspended and dissolved materials. Fixed dustfall is the residue that is left after ignition of the total dustfall sample.

A review of the test results showed that calcium chloride was the most cost-effective control chemical evaluated during the study program. It had the lowest single application costs and was as effective and long lasting as any other chemical. The sensitivity of the results was such that accurate, quantitative estimates of calcium chloride's effectiveness and longevity were difficult to develop. A judgemental review of the data suggested that a single application of calcium chloride would provide an average control effectiveness (i.e. % of uncontrolled dust emissions eliminated by the dust palliative) of about 25% over a period of approximately three weeks.

It was considered that water application once every two hours would provide a level of control effectiveness similar to calcium chloride applied once every three weeks. A single water application provides a measure of dust control for approximately one hour after the water truck has passed. Costs for each dust control technique were estimated to be in the order of $60,000/km for a six month (April to September) dust control season. All of these estimates are for road sections that are in constant use throughout the control season. Costs would be proportionately lower for sections used intermittantly.

5.0 HAULAGE EQUIPMENT

5.1 EQUIPMENT SPECIFICATIONS

511 TIRES

Tire costs have traditionally been one of the largest operating expenses for heavy equipment users. The primary task of the heavy equipment tire today is to haul large loads over ever increasing distances at higher rates of speed. Tire replacement is based on two primary factors - (i) cutting and (ii) interior and exterior wear. These factors are contingent upon several variables:

- wheel load
- vehicle speed
- length of haul
- continuity of operation
- ambient temperature
- inflation pressure
- other tire service
- road conditions
- drive~~n~~r practice
- environment

Only about half of all tires taken out of service are scrapped because they are worn out. The rest fail due to rock cuts and tread separation. A tire's resistance to cutting is a function of tire width, diameter, ply and loading. X

Resistance to cutting is given by the expression:

$$CR = D \times W\ (GA)^2/P \qquad \ldots.(16)$$ X

Where:

CR - resistance to cutting
D - outside diameter of tire
W - crown width ?
GA - T~~h~~read thickness at centre point
P - Maximum rated tire load ?

Equation 16 indicates that resistance to cutting decreases significantly with increased tire t~~h~~read wear. Field data indicate that tire susceptibility to cutting by sharp rock increases with load and inflation pressure since the tire is less able to flex around the rock profile.

On smooth surfaces where cutting is not a factor contributing to tire failure, tread reduction, flexing and material aging will combine to wear out a tire. A key factor in this process is tire loading. Tire life will not materially change if loading is maintained within 5% to 10% of the rated tire loading. A 20% overload, however, will decrease the life potential of a tire by approximately 30%, and a 40% overload is equivalent to a 60% reduction in tire life.

Good tire flotation is achieved by disturbing the ground surface as little as possible. ~~Compound~~ Compared to a bias-ply tire, a radial tire has a ~~mine~~ more uniform ground pressure distribution throughout the tire contact surface. The bias-ply tire, under deflection, has a lower ground pressure in the centre relative to the higher pressures at the edges of the tire contact area, thus has a tendency to dig in at the edges causing ground disturbance. The radial tire, on the other hand, exerts a more uniform ground pressure resulting in less disturbance and better flotation characteristics (EUCLID, undated).

At the Syncrude mine, radial tires are specified for the haul trucks because of the larger ground contact area than conventional tires, resulting in lower bearing pressures, reduced rolling resistance and increased traction (DIONNE, 1987).

Service life of a tire, depends not only on the kind and quality of the tire itself but also on the road surface conditions, applied wheel loads and inflation pressures. For tires operated at rated wheel loads and inflation pressures, the estimated tire life for off-highway trucks is as follows (CATERPILLAR, 1988):

Application Zone	Estimated Service Life
A	4000 - 6000 hr
B	2000 - 4000 hr
C	1000 - 2000 hr

The zones are defined as applications where:

Zone A - almost all tires actually wear through the tread from abrasion
Zone B - tires wear out as above but others fail prematurely due to rock cuts, rips and non-repairable punctures
Zone C - few if any tires ever wear through the tread before having to be discarded, usually from rock cuts.

CATERPILLAR notes that tire life can often be extended by using extra tread type or extra deep tread type. Nevertheless, premature tire failure can occur at anytime due to puncture by st~~a~~umps or sharp rocks.

512 EQUIPMENT MODIFICATIONS

The original specifications for the haulage fleet at the Syncrude minesite were geared to an oilsand operation. Once in service, however, various units of the fleet were modified to increase reliability an efficiency. Some of the more significant modifications, which were necessitated by or related to, directly or indirectly, the conditions of the ground traversed, were as follows (HALE & HOCKER, 1987):

Traction Motors

To increase hauler ability to negotiate soft ground conditions, for example, in the spoil dump and shovel floor areas, Syncrude had its Titan trucks modified to allow the traction motors of the truck's electric drive system, which are normally fed electric power in parallel, to receive power in series by the flick of a toggle switch from the driver's seat. The result is an instantaneous increase in torque to the wheel of about 40% to 45%, albeit at the expense of top speed which is limited to about 11 km/hr. This modification to the standard hauler specifications is ideal in poor ground where high torque is necessary and low speed is acceptable.

Traction Motor Brush Holders

On the Titan hauler 33 - 15B and 15C models, the original brush holders were too lightweight and when overheated would distort sufficiently to jam the brush. This problem was eliminated by installing a heavier brush holder on these units.

Module Frame Reinforcing

Fish plates were added to the engine module frame and an insert tube welded inside the rear torque tube for reinforcement on the 33-15B haulers.

Rear Ride Struts

By installing additional pads and a new type of struts on the B and C units, strut service life increased from 3000 to 8000 hr.

Hydraulic Cylinders

The "C" cylinders on both hauler models were modified with thicker walls to accommodate high spike pressures which occur when dumping.

Axles

Although the Titan 33-15C haulers are fitted with a special tarsand axle which is double the cross-sectional area of the standard axle, the 33-15B units were originally equipped with standard axles which tended to fail prematurely. By machining the traction motor mounting plates to accommodate larger bearings, and changing the bullgear axle shaft and the sun gear, the B models were retrofitted with the large axle.

Overcenter Valves

These valves were redesigned in conjunction with hydraulic cylinder modifications to modify the overcenter action of the dump body caused by the sticky dumping characteristics of oilsand ore and the clay shales of the McMurray Formation.

Air Induction System

The deck supports for the air induction pipes were reinforced to eliminate vibration movement which tended to pull the induction pipes apart, contributing to premature engine failure. In addition, the original fiberglass pipe and clamped rubber elbows on the induction piping system, which readily pulled apart or cracked inducing engine dusting, were replaced with metal pipe.

Dump Body

Some of the stiffener ribs in the dump body of the B units were relocated directly behind the hinge pins to reduce cracking. This modification was taken from the C model design which performed satisfactorily.

Brake System

The brake system of the B haulers was converted to a fail-safe mineral oil system.

Electrical Engine Shutdown System

A manual emergency engine shutdown system, operable from ground level, has been installed on both the B and C units as a back-up to the electrical shutdown system.

5.2 EQUIPMENT MAINTENANCE

521 PREVENTATIVE MAINTENANCE

Preventative maintenance (P.M.) is the most critical aspect of any successful maintenance program. At the Syncrude site, Titan 170 ton haulers undergo a 20 min. P.M. inspection after every 24 hr of operation. Items that do not require immediate maintenance are recorded and rectified when the truck is scheduled for shop service. The haulage units are scheduled for shop lubrication and a mechanical and electrical P.M. service every 250 hr. Increasing levels of lubricant changes and P.M. checks are carried out at various intervals. Engine oil, for example, is changed at 250 hr intervals whereas hydraulic hoist oil is replaced at 500 hr intervals. Similarly, wheel nuts are retorqued every 250 hr while steering is routinely checked every 1000 hr.

Complete rebuilds of the haulage units are also scheduled, the first rebuild program being conducted at approximately 20,000 hr. Each unit is completely disassembled to the frame and rebuilt using new or rebuilt components. In addition, units are scheduled for a major component change at regular intervals. Major components include such items as the axle box assembly, complete engine and generator module, and the front and rear suspensions. The success of this program is evident from an average traction motor life of 17,000 hr, main engine life of 11,500 hr and a fleet mechanical availability of about 84% (DIONNE, 1987). The replacement schedule for Titan haulers is 65,000 hr (HALE & HOCKER, 1987).

Crawler tractors are scheduled for lubrication and mechanical P.M. service after each 250 hr of operation. Because of the abrasive nature of the tarsand overburden, undercarriage life is shortened when compared to conventional surface mining conditions, and hence represents a considerable component of tractor maintenance costs. To keep this cost to a minimum, a comprehensive undercarriage rebuild program has been established, with one maintenance planner assigned full time to undercarriage maintenance duties for the crawler tractor fleet. During the 250 hr P.M. service, all undercarriage components are measured for wear, e.g. track and link height, bushing diameter, grouser height, etc. Track rollers, top carrier rollers and idlers are checked for flange wear and the results recorded. Sprockets are checked for general wear pattern and condition. Track pins and bushings are turned once during the life of the track to ensure maximum life. Track rails are built up where possible when pins and bushings are being replaced (DIONNE, 1987).

Syncrude is actively engaged in an engine oil monitoring program on all units powered by Detroit Diesel Allison 149 series engines which includes the 170 ton Titan haulers. Using monitoring by spectrographic techniques has successfully identified glycol and fuel contamination in many engines prior to failure. However, only limited success has been achieved in determining wear pattern through metal concentrations in the oil. Analysis of oil samples from the planetary compartments of the Titan haulers has, nonetheless, identified the imminent breakdown of planetary gear sets, providing adequate advance warning to allow for scheduled change-out with minimum sequential damage. Where possible, oil sampling is conducted 75 hr prior to the 250 hr service and again during the service to provide maintenance planning with data to effectively plan a 250 hr service time.

In addition to the P.M. described above, unscheduled maintenance is performed as necessary. However, this type of maintenance is undesirable, and is greatly reduced with a good preventative maintenance program (DIONNE, 1987).

522 MAINTENANCE COSTS

Order of magnitude maintenance and service costs for various types of equipment used in road construction and haulage are given in Table 5-1. Table 5-2 lists the range in owning and operating costs for Caterpillar haulers under moderate to severe operating conditions based on customer feedback.

6.0 GOVERNMENT REGULATIONS

6.1 HAULROAD DESIGN

Alberta Regulation 333/75, Part 2, Division 3, Section 180 (ERCB, 1975).

(1) Haulroads which have a gradient in excess of five percent shall have adequate emergency escape roads, which shall:

(a) be spaced throughout the length of the haulroad, and

(b) ensure that a runaway vehicle entering an emergency escape road can be safely brought to rest.

(2) The design of an emergency road shall be submitted to the Board prior to construction.

(3) The Board may instruct a manager to design and construct emergency escape roads on an existing haulroad.

Saskatchewan Regulation 284/78, Part V, Section 410.16 (Saskatchewan, 1978)

(1) The mine employer shall ensure so far as is reasonably practicable that all haulage and access roads at an open pit are designed, constructed and maintained,

(a) to reduce to a minimum the danger from slipping or skidding of vehicles or mobile equipment;

(b) to enable vehicles or mobile equipment to be driven past each other safely;

(c) to avoid steep slopes and sharp bends wherever practicable;

(d) to make provision for emergency runoff lanes or effective impact barriers where steep slopes or sharp bends are unavoidable; and

(e) to make provision for berms or other suitable protection where roads are situated alongside a dangerous slope.

6.2 HAULER EQUIPMENT - SERVICE, PARKING & DYNAMIC BRAKES

Alberta Regulation 333/75, Part 1, Division 7, Sections 94 to 99: "Rubber Tired, Self Proposed Mobile Equipment"

94. (1) In sections 94 to 107, "G.V.W." means the manufacturer's rated gross vehicle weight.

(2) This Division applies to all rubber tired, self proposed equipment used in and around mines for hauling, carrying (including personnel carrying) lifting, hoisting, scraping or like operations and having a G.V.W. greater than 2,000 pounds.

95. (1) All new equipment ordered after the enactment of these regulations shall conform to the standards set by sections 95 to 106 and shall not be used until approved by the Board.

(2) The Board may require that any equipment in use or on order before the enactment of these regulations conforms to these regulations.

(3) Tests, prescribed by the Board and described in the schedules to these regulations shall be carried out to ensure safe operation of existing equipment.

Service Brakes

96. (1) All equipment shall be provided with service brakes capable of

(a) holding the equipment when loaded to the G.V.W., on any grade that it is capable of climbing under its own power, and

(b) safely stopping from normal speeds and holding the equipment when loaded to the G.V.W. on any grade over which it operates.

(2) A representative unit of each equipment type having a G.V.W. in excess of 100,000 pounds or designed for use on steep ramps in a mine shall be subjected to dynamic brake tests as described in the schedules or to alternative tests acceptable to the Board.

97. (1) All equipment fitted with and air or air-over-hydraulic braking system shall be provided with an adequate emergency source of energy which is capable of applying the service brakes and safely stopping and holding the equipment on any grade over which it operates when loaded to the G.V.W.

(2) All equipment fitted with hydraulically actuated service brakes shall have the hydraulic system divided into two or more separate circuits, independently actuated, each of which shall be capable of safely stopping and holding the equipment on any grade over which it operates when loaded to the G.V.W.

(3) All equipment fitted with a divided or dual braking system shall be provided with

(a) an effective warning device to alert the operator whenever one portion of the circuit becomes ineffective, and

(b) controls convenient to the driving position to enable the operator to test the holding power of each portion of the circuit independently of the other portion.

(4) Where the emergency braking system is arranged to cause an automatic application of the service brakes in the event of an accidental loss of pressure in the main brake actuating system, the available brake application pressure shall not fall below 60 percent of the designed system pressure.

(5) Where air or air-over-hydraulic brake systems are fitted to equipment,

(a) all non-braking secondary air circuits shall be supplied through pressure protection valves that will isolate the secondary circuit involved in the event of a sudden pressure drop in the main circuit,

(b) the total volume of air available in the main circuit for normal service brake application shall be not less than 12 times the total displacement volume of all breaker actuators at full travel,

(c) a "wet" reservoir or an air-drying system shall be fitted between the compressor and the first brake service reservoir,

(d) gauges shall be provided that are visible to the operator in the normal driving position and which show the air pressure in the main and emergency air circuits and the brake application pressure,

(e) a visual or visual and audible warning device shall be provided to warn the operator when the air pressure in the main service brake circuit falls below a predetermined pressure, and

(f) check valves shall be used to protect air reservoirs from loss of pressure in the event of leakage on the supply side.

(6) Where auxiliary air reservoirs are provided for modulated emergency brake application under driver control the volume of air in the auxiliary reservoirs shall not be less than six times the total displacement volume of all brake actuators used to develop the emergency brake force.

(7) Machines used in surface mines having a G.V.W. in excess of 100,000 pounds and having air or air-over-hydraulic brake systems shall have front wheel brake control such that the operator can reduce the front wheel brake effort according to road conditions.

(8) The force required on any brake pedal to produce the designed service brake effort shall not exceed 150 pounds.

Parking Brakes

98. (1) Every machine shall be equipped with a mechanically-actuated parking brake capable of holding the vehicle on a 15 percent grade when fully loaded to the G.V.W.

(2) Where a vehicle is designed to travel loaded regularly on grades of 15 percent or over, the parking brake or parking system shall be capable of holding the vehicle stationary on any operating grade or on a 30 percent grade whichever is greater.

(3) The holding power of a parking brake system shall not be affected by any loss of fluid or air pressure in the system or by any dimensional changes in the brake components.

(4) The required parking brake effort shall be produced by a force of not more than 150 pounds for a foot operated system and 90 pounds for a hand operated system.

Alberta Regulation 333/75, Part 1, Division 8, Sections 108 to 119: "Test for Rubber Tired, Self Propelled Mobile Equipment"

New Equipment

108. A representative unit of every rubber tired, self propelled machine of a type not previously used but intended to be used in the Province and having

(a) a G.V.W. in excess of 100,000 pounds, or

(b) designed for use on steep ramps in a mine, shall be subjected to dynamic brake tests.

109. Dynamic brake tests shall be carried out by the manufacturer under the supervision of a professional engineer competent in the field of mechanical engineering and a report of the tests shall be prepared and authenticated by the professional engineer.

110. The tests required by section 108 shall be conducted with the vehicle loaded to the manufacturer's G.V.W. on a straight test road having a hard, dry surface with a uniform grade not less than 5 percent nor greater than 15 percent.

111. In a test required by this ~~d~~Division, measurements shall be made of

(a) the distance travelled by the vehicle following application of the service brakes to the maximum extent possible, and

(b) the forward speed of the vehicle at the time of application of the service brakes.

112. In a test required by this Division,

(a) at least four measurements of the stopping distance at different speeds shall be made using the same vehicle,

(b) the measurements shall be with no intermediate adjustments of the braking assemblies,

(c) time for the brake equipment to cool between tests may be allowed, and

(d) the range of forward speeds for the vehicle tests shall be not less than 5 miles per hour and not greater than 25 miles per hour.

113. A report of the dynamic brake tests shall be submitted to the Board and shall contain

(a) date of the test,

(b) vehicle model, number and serial number,

(c) detail of load,

(d) description, location, gradient and surface condition of the test road,

(e) table of stopping distance, forward speed and test time interval, and

(f) identification of the professional engineer responsible for the supervision and the tests.

Existing Equipment

114. Every rubber tired, self propelled machine shall be subject to an annual dynamic brake test.

115. The annual dynamic brake test shall be carried out under the supervision of a technician competent in the field of mechanical engineering.

116. A report of the tests shall be inscribed in the vehicle logbook by that technician.

117. The annual dynamic break test shall be conducted with the vehicle loaded approximately to the manufacturer's G.V.W. on a straight level road having a hard dry surface.

118. In an annual dynamic brake test, a measurement shall be made of the distance travelled by the vehicle following application of the service brakes to the maximum extent possible and the forward speed of the vehicle at the time of application shall be noted.

119. The vehicle logbook entry shall contain

(a) date of test,

(b) detail of load,

(c) description and location of test road,

(d) stopping distance and forward speed, and

(e) identification of the technician supervising the test.

British Columbia Coal Mine Regulations, RS Chap. 52, Section 244, Item 6:

A truck or loader when newly put into service and having a manufacturer's gross vehicle weight in excess of 100,000 pounds shall have

(a) a manufacturer's nameplate affixed to the inside of the cab in full view of the operator, and the nameplate shall show the

(i) vehicle serial number;

(ii) maximum rated load capacity; and

(iii) maximum grade on which the vehicle may safely operate;

(b) its braking system and steering system designs submitted to and accepted by the chief inspector; and

(c) any modifications affecting the steering, braking systems or design to increase weight carrying capacity approved by the manufacturer and accepted by the chief inspector.

British Columbia, ibid, Section 246 "Brakes-Service, Air and Parking":

(1) No person shall operate or put in motion a vehicle or mobile equipment unless it is equipped with brakes as set out in subsections (2) to (6).

(2) A power driven vehicle shall be equipped with a suitable service brakes system capable of safely stopping and holding the vehicle, within the limits of traction of the braked wheels, on a grade which it is capable of climbing under its own power when loaded to the manufacturer's gross vehicle weight and, where the inspector considers it necessary, an independent means of retardation shall be provided in addition to the above braking system.

(3) A motor vehicle using air or air over hydraulic brakes shall, in addition to the normal operating air supply, be equipped with an adequate emergency source of energy capable of applying the service brakes so as to safely stop and hold the vehicle when loaded to the manufacturer's gross vehicle weight on any grade over which it operates.

(4) A suitable warning device shall be maintained in each vehicle referred to in subsection (3) that will readily warn the driver whenever the available air pressure drops to its lowest safe operating pressure.

(5) No vehicle fitted with hydraulically actuated service brakes shall be put into use for the first time unless the hydraulic system is split into 2 or more separate and independently operated circuits, each of which is capable of safely stopping and holding the vehicle under any operating condition of load, grade and speed, and an alarm device is provided in the cab of the vehicle to warn the operator of a failure of any hydraulic circuit.

(6) A vehicle shall be equipped and maintained with an effective mechanical parking brake, and, where this brake provides the only emergency means of stopping in the event of failure of the service brakes, it shall be capable of safely stopping and holding the vehicle under any operating condition.

(7) A unit of power driven mobile equipment fitted with a fluid drive transmission shall be provided with an interlocking system whereby the unit cannot be started and put into motion unless the range transmission is returned through the neutral position .

(8) Clearly marked emergency runoff lanes, or effective impact barriers, shall be provided at suitable locations on all roadways used for the transport of persons or for haulage purposes in which the grade exceeds 5%.

British Columbia, ibid, Section 247 "Air Brakes and Power Steering":

(1) Unless otherwise approved by the inspector, where air brakes are used they shall be installed and maintained according to the Highway (Industrial) Act.

(2) Where a rubber tired motor vehicle depends on power for steering and where the loss of such power may prevent the vehicle from being steered manually, an auxiliary device shall be installed to enable the driver to steer the vehicle for a sufficient period of time to bring it to a safe stop.

Saskatchewan Regulation 284/78, Part XXIII, Sections 446.06 and 446.08:

446.06 The employer at a mine shall ensure that,

(a) every motor vehicle or unit of mobile equipment used at a mine is equipped with a service brake capable of safely stopping and holding that motor vehicle or unit of mobile equipment when loaded to the manufacturer's recommended gross weight on any grade which it is capable of climbing under its own power when so loaded;

(b) every vehicle or unit of mobile equipment is provided with an effective parking brake that is capable of holding the vehicle or mobile equipment under any operating condition;

(c) where an inspector considers it necessary to ensure the safety of workers the inspector may require that,

(i) an independent means of regardation shall be provided;

(ii) an emergency braking system shall be provided in addition to the requirements of clause (a) and (b).

446.08(1) Without prejudice to the generality of section 446.06 the employer at a mine shall not permit the operation at the mine of any rubber tired vehicle used to transport material with a gross weight exceeding fifty thousand kilograms or any unit of mobile equipment exceeding twenty-five thousand kilograms gross weight put into service at that mine for the first time after January 1, 1979 unless the service braking system,

(a) has been physically tested at the maximum severity of any operating condition or a similar vehicle or item of mobile equipment has been so tested and found to bring the vehicle or equipment to rest in a satisfactory manner; and

(b) is physically tested at the maximum severity of normal operating conditions at intervals not exceeding twelve months and found to be satisfactory.

(2) The chief inspector may specify in writing the method of testing to be used in subsection (1) and the standard to be achieved by any vehicle or item of mobile equipment for any mine or class of mines.

(3) The employer at a mine shall ensure that every motor vehicle put into service at that mine for the first time after January 1, 1979 for the transport of ~~one~~ ore or waste at an open pit mine in addition to the requirements of subsection (1) satisfies the following requirements,

(a) every such motor vehicle using air or air-over hydraulic brakes is,

(i) in addition to the normal operating air supply equipped with an adequate emergency source of energy capable of applying the service brakes so as to safely stop and hold the vehicle when loaded to the manufacturer's recommended gross weight on any grade over which it operates;

(ii) be equipped with a suitable device that will give adequate warning to the operator whenever the available air pressure drops to its lowest safe operating pressure;

(b) every such vehicle using hydraulically operated service brakes shall be equipped with the hydraulic system split into two or more separate and independently operated circuits each of which is capable of safely stopping and holding the vehicle under any operating condition of load, grade and speed and an alarm system shall be provided to warn the operator of a failure in the hydraulic circuit.

6.3 HAULER EQUIPMENT - TIRES

British Columbia, Coal Mine Regulations, RS Chap. 52, Section 249, "Inflation of Tires":

Whenever work is to be performed on the pneumatic tires of heavy duty equipment, the manager shall provide safety devices and enforce adequate safety precautions to protect workers if the tire and rim assembly spring under inflation.

Saskatchewan Regulation 284/78, Part XXIII, Section 446.22, "Provisions for Working on Tires":

Wherever work is to be performed on the pneumatic tires of any equipment the employer at a mine,

(a) shall provide suitable safety guards or other devices to prevent injury to workers should the tire and rim assembly spring under inflation; and

(b) shall require that a worker working on any tire where the inflation of that tire could cause the rim assembly to spring uses such as a safety device.

6.4 HAULROAD - TRAFFIC CONTROLS

Alberta Regulation 333/75, Part 2, Division 1, Section 170, "Blasting Warning":

Where blasting is being conducted the following signs shall be displayed

(a) Approach Signs:

BLASTING

DRIVERS MUST TURN OFF MOBILE TRANSMITTERS
UNTIL FURTHER POSTED NOTICE.
WATCH FOR IT ON LEFT SIDE

(b) Departure Sign:

YOU MAY RESUME TRANSMITTING.
THANK YOU.

British Columbia Coal Mine Regulation, RS Chap. 52, Section 245, Item 2:

(2) The owner, agent or manager of a mine shall prepare a traffic control scheme for the operation and shall have it accepted by the inspector, and the scheme shall show the maximum allowable speeds for the vehicles in use, rules for passing, "stop" and "yield" locations, priority rules for various vehicles, rules for night operation, maximum operating grades, emergency runoff protection and other information required by the inspector.

Saskatchewan Regulation 284/78, Part XXIII, Section 446.26

If in the opinion of an inspector a hazard or potential hazard exists through inadequate traffic control, the inspector may require the mine employer to institute a traffic control scheme which shall prescribe where applicable,

(a) the maximum allowable speed for any vehicle or class of motor vehicles or mobile equipment in use;

(b) maximum operating grades;

(c) the location and nature of control signs;

(d) the route to be taken by any vehicle;

(e) the priority to be established for any class of vehicle;

(f) any other provision required by the inspector.

Saskatchewan, ibid, Part XI, Section 422.24 "Transportation of Explosives":

422.24(1) This section shall apply on the surface of a mine and underground in a mine as required by section 422.30, subsection (2).

(2) The employer at a mine shall ensure that,

(a) every motor vehicle used for carrying explosives or blasting agents is maintained in sound mechanical conditions;

(b) the word "EXPLOSIVES" is painted in letters at least one hundred and fifty millimetres in height in luminous paint to be clearly visible from the back, front and sides of the vehicle;

(c) the metal parts of such vehicle that may come in contact with containers of explosives or blasting agents shall be covered with suitable material.

(3) The employer at a mine shall not permit any other material to be carried in or on any vehicle in which explosives or blasting agents are being carried.

(4) The employer at a mine shall not permit any motor vehicle to be loaded with more than eighty percent of its rated carrying capacity when carrying explosives or blasting agents.

(5) The employer at a mine shall ensure that any explosives or blasting agents carried by a vehicle is adequately secured.

(6) The employer at a mine shall ensure that no detonator is carried in the same vehicle as any other explosive or blasting agent except as provided for in section 422.32, subsection (1).

(7) The employer at a mine shall ensure that any vehicle carrying explosives or blasting agents is not left unattended.

(8) The employer at a mine shall not permit any worker other than those workers necessary for the handling of explosives or blasting agents to travel on a vehicle that is carrying explosives or blasting agents.

(9) The employer at a mine shall not permit any worker to smoke on a vehicle that is transporting explosives or blasting agents.

(10) The employer at a mine shall ensure that the engine of any vehicle that is carrying explosives or blasting agents is not left running during the loading or unloading of explosives.

(11) The employer at a mine shall ensure that a vehicle is not refuelled when carrying explosives or blasting agents except in an emergency and he shall report the details of any such occurrence to the chief inspector.

(12) The employer at a mine shall cause any explosives or blasting agents that are not required immediately to be returned to the magazine and not to be left in any vehicle.

(13) The employer at a mine shall require the driver of any vehicle carrying explosives or blasting agents to drive in a careful manner and to stop the vehicle before crossing any railway track.

(14) When any vehicle is used to carry any explosives or blasting agents at a mine, the employer at a mine shall ensure that it is in the charge of a component worker.

7.0 LIST OF REFERENCES

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TABLE 2-1

Producing Surface Mines in Western Canada

Mine	Operator	Owner	Product	1987 Production (M Tonnes)
Balmer	Westar Mining Ltd.	Westar Mining Ltd.	Coal	5.1
*Bienfait	Bienfait Coal Co. Ltd.	Luscar Ltd.	Coal	2.0
*Boundary Dam	Manitoba & Saskatchewan Coal (1984) Ltd.	Luscar Ltd.	Coal	1.5
*Bullmoose	Bullmoose Operating Corp.	Teck Corporation	Coal	1.7
Coal Mountain	Byron Creek Collieries	Esso Resources Canada Ltd.	Coal	0.8
*Coal Valley	Luscar-Sterco (1977) Ltd.	Luscar Ltd.	Coal	1.7
Costello	Prairie Coal Ltd.	Manalta Coal Ltd.	Coal	0.4
*Fording River	Fording Coal Limited	Fording Coal Limited	Coal	5.0
*Greenhills	Westar Mining Ltd.	Westar Mining Ltd.	Coal	3.2
Gregg River	Gregg River Resources Ltd.	Manalta Utilities Corp.	Coal	1.8
Highvale	Manalta Coal Ltd.	TransAlta Utilities Corp.	Coal	12.1
*Line Creek	Crows Nest Resources Ltd.	Crows Nest Resources Ltd.	Coal	1.7
Luscar	Cardinal River Coals Ltd.	Luscar Ltd. & Consolidation Coal Co.	Coal	1.5
Montgomery	Manalta Coal Ltd.	Manalta Coal Ltd.	Coal	1.2
*Obed	Obed Mountain Coal Co. Ltd.	Unocal Canada Limited & Norcen Energy Co. Ltd.	Coal	0.9
*Paintearth	Forestburg Collieries (1984) Ltd.	Luscar Ltd.	Coal	1.7
Poplar River	Prairie Coal Ltd.	Manalta Coal Ltd.	Coal	3.6
*Quintette	Quintette Coal Ltd.	Denison Mines Ltd. (50%)	Coal	4.4
*Smoky River	Smoky River Coal Ltd.	Smoky River Holdings Ltd.	Coal	0.9
Utility	Prairie Coal Ltd.	Saskatchewan Power Corp.	Coal	2.5
Vesta	Manalta Coal Ltd.	Alberta Power Limited	Coal	1.1
*Whitewood	Fording Coal Limited	TransAlta Utilities Corp.	Coal	2.2
*Syncrude	Syncrude Canada Ltd.	Syncrude Canada Ltd.	Oil Sand	105
*Suncor	Suncor Inc.	Suncor Inc.	Oil Sand	35 (est)

* Mines canvassed in this study.

TABLE 2-2

Weather Conditions at Different Minesites

Mine	Meteorological Station		Frost-Free Days/Year	Mean Annual Temp ^{o}C	Avg. Annual Precipitation (mm)
	Location	Dist. from Mine (km)			
Boundary Dam	Weyburn, Sask.	50	111	3.1	382
Line Creek	At Minesite	-	129	3.0	410
Paintearth	Forestburg, Alta.	25	137	3.0	385
Quintette	At Minesite	-	n.a.	1.4	617
Suncor, Syncrude	Fort McMurray Airport	60, 80	84	-0.2	472
Whitewood	Stoney Plain, Alta.	40	137	2.4	529

n.a. - not available

TABLE 2-3

Types of Stripping and Mining Equipment

Equipment	Mines Using
Overburden/Interburden Stripping	
o Shovel/Loader	11
o Dragline	6
o Scraper/Dozer	7
Coal/Tarsands Mining	
o Shovel/Loader	13
o Dragline	3
o BWE/BWR	2
o Easiminer	1

TABLE 2-4

Haulage Equipment

	Models Assigned to	
Make	Waste Haul	Product Haul
Atlas/Cat 776	-	Bellydump
Cat	637D,777,785,789	789
Cat Scraper	637D/E	637D/E
Euclid	-	CH120, B70
Euclid/Atlas	-	203LDT/CH-70
Goodbarry	-	CP2400
Kentworth	-	850
Komatsu	HD 1200M	-
Lectra Haul	M33, M85	M24
Pacific	-	P-12
Terex	33-11D,-15B,-15C	33-11D,-15B,-15C
Unit Rig	M100	M100
Wabco	85D,120D,120C,170D	120B,120C,170D

TABLE 2-5

Haul Road Length

Material	Cumulative Length (km)
In-Pit	
Product Haul	10
Waste Haul	33
Common Haul	5.5
Total In-Pit =	48.5 km
Ex-Pit	
Product Haul	108.5
Waste Haul	62.5
Common Haul	7
Total Ex-pit =	178 km

TABLE 2-6

Annual Traffic Loading on Ex-Pit Roads

Mine	Truck Weight (t)		Loaded Trucks/hr	Time Worked hr/yr	Road Loading (Mta)	
	Empty	Loaded			Product	Waste
1	96	238	1.0	6120	2.0	
	60	150	3.0	6120	3.9	
	106	260	1.2	6120		2.8
	60	150	1.5	6120		2.0
	48	82	1.2	6120		1.0
2	41	105	8.0	5600	6.5	
3	102	170	4.2	7455	8.5	
	102	222	5.9	7455		14.3
	124	294	1.7	7455		5.3
4	108	188	12.0	7800	27.7	
	154	256	48.0	7800		153.5
5	55	132	5.9	6532		7.2
	81	190	20.6	6532		36.4
	93	230	20.6	6532		43.4
	35	75	7.0	6532	5.0	
	40	80	7.0	6532	5.5	
6	120	250	6.5	4000	9.6	
7	30	69	8.0	7968	6.3	
8	58	135	32.4	8760		54.8
	56	133	9.6	8760		15.9
9	41	105	15.0	3500	7.7	
10	101	255	8.8	8520	27.0	
	53	130	0.5	8520	0.7	
	50	85	0.8	8520	0.9	
	101	255	73.0	8520		223.8
	53	130	3.7	8520		5.8
	50	85	6.3	8520		7.1

TABLE 2-7

Annual Traffic Loading on In-Pit Roads

Mine	Truck Weight (t) Empty	Truck Weight (t) Loaded	Loaded Trucks/hr	Time Worked hr/yr	Road Loading (Mta) Product	Road Loading (Mta) Waste
1	96	238	1	6120	2.04	
	60	150	3	6120	3.86	
	106	260	1.23	6120		2.76
	60	150	1.54	6120		1.98
	48	82	1.23	6120		0.98
2	41	105	8	5600	6.54	
3	102	170	4.2	7455	8.52	
	102	222	17.73	7455		42.8
	124	294	5.07	7455		15.8
4	108	188	12	7800	27.71	
	154	256	48	7800		153.5
5	55	132	5.88	6532		7.18
	81	190	20.56	6532		36.39
	93	230	20.56	6532		43.38
	35	75	7	6532	5.03	
	40	80	7	6532	5.49	
6	120	250	6.5	4000	9.62	
7	30	69	8	7968	6.31	
	52	121	7.27	7968		10.02
	30	69	2.72	7968		2.15
8	58	135	58.63	8760		99.13
	56	133	17.37	8760		28.75
9	41	105	15	3500	7.66	
10	101	255	8.79	8520	26.96	
	53	130	0.45	8520	0.7	
	50	85	0.76	8520	0.86	
	101	255	72.96	8520		223.77
	53	130	3.74	8520		5.8
	50	85	6.3	8200		7.14
11	106	255	30	8760		94.87
	106	255	25	8760		79.06
	115	292	3	8760		10.7

TABLE 2-8

Traffic Loading and Expected Road Life

Mine	Road Location	Material Hauled	(Mta) Road Loading	(months) Expected Life
7	Ex-pit	Product	6.3	120
9	Ex-pit	Product	7.7	120
6	Ex-pit	Product	9.6	60
5	Ex-pit	Product	10.5	24
4	Ex-pit	Product	27.7	120
10	Ex-pit	Product	28.5	24
8	Ex-pit	Waste	70.7	2
5	Ex-pit	Waste	87.0	12
4	Ex-pit	Waste	153.5	48
10	Ex-pit	Waste	236.7	9
1	In-pit	Product	5.9	12
7	In-pit	Product	6.3	2
9	In-pit	Product	7.7	3
3	In-pit	Product	8.5	12
6	In-pit	Product	9.6	48
4	In-pit	Product	27.7	3
10	In-pit	Product	28.5	3
1	In-pit	Waste	5.7	12
7	In-pit	Waste	12.2	2
3	In-pit	Waste	58.6	12
5	In-pit	Waste	87.0	84
8	In-pit	Waste	127.9	2
4	In-pit	Waste	153.5	3
11	In-pit	Waste	184.5	24
10	In-pit	Waste	236.7	3

TABLE 2-9

Haulroad Geometry

Item	Mine Number 1	2	3	4	5	6	7	8	9	10	11	12	13
Max. Grade (%)	8	10	10	10	10	12	8	10	8	7.5	8	10	10
Max. Curve Superelevation (%)	0	2	4	4	6	3	3	5	4	6	10	3	3
Max. Road Cross-Slope (%)	0	1	2	3	2	2	2	4	2	4	3	1	?
Min. Running Width (m)*	36	20	30	25	20	21.3	21.3	45	21	28	25	30	30
Ditch sizing	R	?	R	D	D	D	D	?	D	R	D	D	R
Avg. Height Safety Berms (m)	1.5	?	1.5	3	2	1.5	2.8	4	?	2	1.5	1.5	2
Max. Breaking Distance Limitation (m)	30	30	61	60	45	45	14***	?	45	48	?	30	?
Run-Away Lanes													
- Max. Gradient (%)	12	N/A	10	14	20	N/A	20	N/A	N/A	25	N/A	N/A	16
- Avg. Length (m)	100	N/A	100	100	75	N/A	80	N/A	N/A	50	N/A	N/A	V
- Spacing (m)	350	N/A	200	30**	FF	N/A	?	N/A	N/A	400	N/A	N/A	V

Legend

FF - Field Fit
? - Data not Available
V - Varies
D - Designer Experience
R - Provincial Regulations
N/A - Not applicable

* 2 Lane Road
** Elevation Difference
*** On Level Ground

TABLE 2-10

Typical Road Cross-Section and Water Crossing Construction

Mine No.	Base Course	Surface Course	Water Crossings
1	ROM Sandstone	-150 mm size ROM sandstone	CMP culvert
2	ROM shale & mudstone & 0.6 to 1.0 m layer of sandy clay	-75 mm size gravel	CMP culvert with 1.5 m cover
3	ROM sandstone (40%) & mudstone (60%	-50 mm size crushed rock (occasional use)	o CMP culvert (less than 2 m deep) o Rock drain with -1000 mm size rock (more than 2 m deep)
4	ROM sandstone (70%) & mudstone (30%)	150 mm layer of -45 mm size crushed rock	o CMP culvert (@ river crossings) o sandstone rock drain with -600 mm size rock (@ Creek Crossings)
5	ROM sandstone (50%) & mudstone (50%)	None	Rock drain with 600 mm to 1000 mm rock size
6	1 m layer of ROM	Imported gravel	(data not available)
7	1.5 m layer of ROM (50% sandstone)	75 mm layer of -19 mm size crushed rock	Rock drains
8	Blasted limestone	Sand & 50 mm - 75 mm layer of clay	(data not available)
9	ROM sandstone and gravel	ROM gravel	None
10	1 m layer ROM	Layer of fine spoil	(data not available)
11	Free draining pit-run gravel Thickness as per CBR charts Min. Thickness = 0.5 m	-75 mm size crushed gravel Thickness as per CBR charts	CMP culvert with minimum cover of 0.5 x culvert diameter
12	ROM & 0.6 m layer of +100 mm size gravel	100 mm layer of -50 mm size & 100 mm layer of -19 mm size gravel	(data not available)
13	1 to 2 m layer of ROM material (mostly sandstone)	100 mm to 150 mm layer of crushed rock	Rock drain with 600 mm to 1000 mm rock size

TABLE 2-11

Road Construction and Maintenance Equipment

Type	Make	Model	Total in Use	No. of Mines Using
Backhoe	Caterpillar	235	1	1
Backhoe	Koehring	466E	1	1
Dozer	Caterpillar	D8	12	3
Dozer	Caterpillar	D8L	2	1
Dozer	Caterpillar	D9H	1	1
Dozer	Caterpillar	D9L	27	5
Dozer	Caterpillar	D9N	5	2
Dozer	Caterpillar	D10N	12	2
Dozer	Caterpillar	D11	11	1
Dozer	Caterpillar	834/824C	7	1
Dozer	Komatsu	K155	2	1
Dozer	Komatsu	D355	11	3
Dozer	Komatsu	D375	7	4
Grader	Caterpillar	16G	45	11
Grader	Caterpillar	31G	2	1
Grader	Champion	100T	1	1
Grader	O&K	-	1	1
Packer	Caterpillar	824	1	1
Packer	Caterpillar	825	5	2
Packer	Caterpillar	834B	1	1
Scraper	Caterpillar	627	4	2
Scraper	Caterpillar	631C	6	2
Scraper	Caterpillar	637	14	5
Waterboy	Caterpillar	637	4	2
Water truck	Euclid	R35	5	3
Waterwagon	Caterpillar	631	4	2

TABLE 2-12

Materials Used for Road Construction

Construction Materials	No. of Mines Using	%
Common Fill	7	54
Random Mine Spoil	6	46
Free-draining Mine Spoil	6	46
Crushed Rock	8	62
Blasted Rock	1	8
Sand & Gravel	1	8
Coal Ash/Tarsand Rejects	2	15

TABLE 2-13

Materials Used for Road Wearing Surface

Surface Course	No. of Mines Using	%
Fine Crushed Rock	7	54
Coarse Gravel	7	54
Pit-run Gravel	1	8
Sand	1	8
Mine Spoil	1	8
Common Fill	1	8
Tarsand Rejects	1	8
Coal Rejects	1	8
Rollcrete (trial basis)	1	8
In Situ Formations	5	38

TABLE 2-14

Symptoms of Haulroad Deterioration

Symptom	No. of Mines Experiencing	%
Soft Ground, Rutting	9	69
Settlement	3	23
Slippery when wet	12	92
Frost heave	8	62
Loose Surface Course	8	62
Washboarding	4	31
Potholes	2	15

TABLE 2-15

Causes of Road Surface Deterioration

Cause of Deterioration	No. of Mines Reporting	%
Dust/Binder Deficiency	13	100
Gravel Deficiency	2	15
Heavy Traffic Volume	1	8
High Groundwater Levels	1	8
Ice & Snow	5	38
Operator Driving Techniques	3	23
Poor Base Course Compaction	2	15
Precipitation/Runoff	11	85
Spring Breakup	7	54
Vehicle Spillage	4	31

TABLE 2-16

Measures Taken to Improve Road Trafficability

Remedial Measures	No. of Mines Using	%
Grading	13	100
Resurfacing	12	92
Road Realignment	6	46
Plowing-scarifying-sanding	13	100
Raising Grade	10	77
Excavate/Backfill Soft Spots	6	46

TABLE 2-17

Measures Used for Dust Suppression

Dust Suppressant	No. of Mines Using	%
Water Sprinkling	13	100
Saline groundwater sprinkling	1	8
Chemical Treatment	5	38
Oil Sprinkling	4	31
Potash Binder	1	8

TABLE 2-18

Road Maintenance Frequency

	Mine No.												
	1	2	3	4	5	6	7	8	9	10	11	12	13
(i) Ex-Pit Roads													
o Clean/Regrade	C	W	C	C	C	C	C	C	C	C	C	C	C
o Repair	A	AR	AR	AR	M	M	AR	M	AR	AR	AR	M	AR
o Dust Suppression	C	AR	AR	C	2A	C	AR	C	C	C	AR	C	C
(ii) In-Pit Roads													
o Clean/Regrade	C	C	C	C	C	C	C	C	C	C	C	C	C
o Repair	A	?	AR	AR	C	M	AR	M	AR	A	AR	M	AR
o Dust Suppression	C	AR	AR	C	?	C	AR	C	C	AR	AR	C	C
(iii) PM Program in Place	N	N	N	N	Y	N	Y	N	Y	N	N	N	N

Legend
AR - As Required
A - Annual
2A - Bi-Annual
C - Continuous
M - Monthly
N - No
PM - Preventative Maintenance
W - Weekly
Y - Yes
? - Data not available

TABLE 2-19

Traffic Control Installations

	No. of Mines Using	%
Automated fleet monitoring	2	15
Culvert crossing markers	8	62
Curve & intersection signs	6	46
Information signs	1	8
Limited access designators	11	85
Manned security gate	1	8
Roadside reflector posts	2	15
Roadside safety berms	12	92
Runaway lanes	8	62
Speed limit signs	11	85
Stop signs/traffic lights	12	92
Traffic control signs	11	85

TABLE 4-1

Recommended Superelevations for Horizontal Curves

(a) Data After KAUFMAN & AULT (1977)

Radius of Curve (ft)	Vehicle Speed (mph) 10	15	20	25	30	35 and above
50	4	4				
100	4	4	4			
150	4	4	4	5		
250	4	4	4	4	6	
300	4	4	4	4	5	6
600	4	4	4	4	4	5
1000	4	4	4	4	4	4

(b) Data After CATERPILLAR (1988)

Radius of Curve (ft)	Vehicle Speed (mph) 10	15	20	25	30	35	40	45
50	13.4	30.2						
100	6.7	15.6	26.8					
200	3.4	7.8	13.4	20.9	30.2			
300	2.2	5.2	8.9	14.0	20.1	27.4	33.2	
400	1.7	3.9	6.7	10.5	15.1	20.5	26.8	33.9
500	1.3	3.1	5.4	8.4	12.1	16.4	21.4	27.1
600	1.1	2.6	4.5	7.0	10.0	13.7	17.9	22.6
700	1.0	1.9	3.8	6.0	8.6	11.7	15.3	19.4
800	0.9	1.7	3.4	5.2	7.5	10.3	13.4	17.0
900	0.7	1.6	3.0	4.7	6.7	9.1	11.9	15.1
1000	0.7	1.4	2.7	4.2	6.0	8.2	10.7	13.6

Note: Superelevations in %

TABLE 4-2

Minimum Turning Radii for Various Haulers

Hauler	(lb) GVW	(ft) Turning Radius	Reference
CATEGORY 1	<100,000	19.00	KAUFMAN & AULT (1977)
EUCLID R-25	39,200	24.96	EUCLID (undated)
TEREX 33-03B	38,000	30.67	EUCLID (undated)
FAUN K24.2	36,400	29.29	EUCLID (undated)
CATEGORY 2	100,000 - 200,000	24.43	KAUFMAN & AULT (1977)
EUCLID R-35	129,300	26.00	EUCLID (undated)
TEREX 233-05B	109,500	24.04	EUCLID (undated)
TEREX 33-07	151,600	28.71	EUCLID (undated)
WABCO 35D	131,140	24.50	EUCLID (undated)
CAT 769C	149,000	30.33	CATERPILLAR (1988)
EUCLID R-50	179,450	31.00	EUCLID (undated)
WABCO 50B	177,240	29.00	EUCLID (undated)
EUCLID R-85	282,800	36.10	EUCLID (undated)
WABCO 85 D	289,300	34.50	EUCLID (undated)
TEREX 33-11C	286,400	35.35	EUCLID (undated)
TEREX 33-11D	290,800	33.50	EUCLID (undated)
UNIT RIG M-85	287,150	30.00	EUCLID (undated)
CAT 773B	204,000	38.50	CATERPILLAR (1988)
CAT 777B	324,000	42.25	CATERPILLAR (1988)
EUCLID R-100	248,900	41.00	EUCLID (undated)
UNIT RIG M-100	331,500	30.50	EUCLID (undated)
CATEGORY 4	400,000+	38.88	KAUFMAN & AULT (1977)
EUCLID 120E	419,600	38.08	EUCLID (undated)
WABCO 120C	418,235	40.50	EUCLID (undated)
TEREX 33-14	415,000	36.33	EUCLID (undated)
TEREX 34-11C	481,000	41.16	MONENCO FILES
KRESS CH-160	458,200	31.04	MONENCO FILES
CAT 785	508,000	50.17	CATERPILLAR (1988)
CAT 789	643,000	49.58	CATERPILLAR (1988)
EUCLID R-170	563,900	43.79	EUCLID (undated)
TEREX 33-15B	574,400	46.42	EUCLID (undated)
UNIT RIG MARK 36	550,000	41.50	EUCLID (undated)
EUCLID CH-150	505,600	41.00	EUCLID (undated)

TABLE 4-3

Design Widths for Horizontal Curves
(after KAUFMAN & AULT, 1977)

(a) Single Unit Haulers

Curve Radius on Inner Edge of Pavement (R) feet	One-lane Road				Two-lane Road				Three-lane Road				Four-lane Road			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Minimum	29	34	45	70	51	60	79	123	73	86	113	176	95	112	147	229
25	27	34	44	68	48	60	76	119	68	86	109	170	89	111	142	221
50	25	31	41	63	44	54	72	110	63	77	103	158	82	100	134	205
100	24	29	39	59	42	51	69	103	60	73	99	147	78	95	128	192
150	24	29	39	58	41	50	68	101	59	72	97	145	77	94	126	188
200	23	29	38	57	41	50	67	101	59	71	96	144	76	93	125	187
Tangent	23	28	37	56	40	48	65	98	57	69	93	140	74	90	120	182

(b) Articulated Haulers

Curve Radius on Inner Edge of Pavement (R) feet	One-lane Road				Two-lane Road				Three-lane Road				Four-lane Road			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
25	38		68	86	66		119	151	95		170	215	123		221	280
50	32		57	71	56		99	124	80		142	177	105		184	231
100	28		48	58	50		83	101	71		119	144	92		154	187
150	27		44	52	47		76	91	68		109	130	88		142	168
200	26		42	49	46		73	85	66		104	122	85		135	158
Tangent	25		41	41	44		71	72	63		102	103	81		133	133

NOTE: 1 indicates category 1 vehicle: <100,000 pounds GVW.
2 indicates category 2 vehicles: 100,000 to 200,000 pounds GVW.
3 indicates category 3 vehicles: 200,000 to 400,000 pounds GVW.
4 indicates category 4 vehicles: >400,000 pounds GVW.
Design widths in feet.

TABLE 4-4

Presumptive Bearing Capacity of Various Materials

Material	Bearing Capacity (psi)
Hard, sound rock	800+
Medium hard rock	400-600
Hardpan overlying rock	130-180
Dense gravel; very dense sand and gravel	120-160
Soft rock	100-120
Medium dense to dense sand and gravel	80-100
Hard, dry overconsolidated clay	60-80
Loose, coarse to medium sand, medium dense fine sand	30-60
Compact sand-clay soils	30-40
Loose fine sand, medium dense sand-silt soils	15-30
Firm or stiff clay	10-20
Loose saturated sand, medium soft clay	5-10
Muskeg, peats, marsh soils	0-5
Loose to medium dense mine spoil	5-75

TABLE 4-5

Haulroad Section Based on CBR Chart

Layer	Typical Material	CBR (%)	Total Fill Cover* (in)	Layer Thickness* (in)
Surface Course	Crushed Rock	95	--	8
Base Course	Pitrun Sand & Gravel	60	8	7
Sub-base	Till, Mine Spoil	25	15	36
Subgrade	Firm Clay	4	51	--

* For wheel load of 100,000 lb.

TABLE 4-6

Typical Road Adhesion Coefficients
(after KAUFMAN & AULT, 1977)

Road Surface		Road Adhesion Coefficients			
		Rubber Tire[1]	Track[1]	Rubber Tire[2]	Rubber Tire[3]
Concrete:	New	0.90	0.45	0.80-1.00	0.8-0.90
	Travelled			.60- .80	
	Polished			.55- .75	
	Wet			.45- .80	0.80
Asphalt:	New			.80-1.00	0.80-0.90
	Travelled			.60- .80	
	Polished			.55- .75	
	Excess tar			.50- .60	
	Wet			.30- .80	.5- .70
Gravel:	Packed and oiled			.55- .85	.60
	Loose	.36	.50	.40- .70	
	Wet			.40- .80	
Rock:	Crushed			.55- .75	
	Wet			.55- .75	
Cinders:	Packed			.50- .70	
	Wet			.65- .75	
Earth:	Firm	.55	.90		.68
	Loose	.45	.60		
	Wet				.55
Clay Loam:	Dry	.55	.90		
	Rutted	.40	.70		
	Wet	.45	.70		
Sand:	Dry	.20	.30		
	Wet	.40	.53		
Coal:	Stockpiled	.45	.60		
Snow:	Packed	.20	.25	.30- .55	.20
	Loose			.10- .25	
	Wet			.30- .60	
Ice:	Smooth	.12	.12	.10- .25	.10
	Sleet				.10
	Wet			.05- .10	

1 SAE (1973)
2 CATERPILLAR (1970)
3 TABOREK (1957)

TABLE 4-7

Rolling Resistance Model Tests on Towed Wheel

Soil	Tire Load (lb)	Tire Pen. (in)	Tow Force (lb)	Rolling Resist. % Meas.	Rolling Resist. % Est.	Reference
Clay	5918	1.16	1186	20.0	3.7	Crenshaw et al (1971)
Clay	6151	1.57	1520	24.7	4.4	Crenshaw et al (1971)
Clay	5431	0.63	347	6.4	2.9	Crenshaw et al (1971)
Clay	5556	0.96	796	14.3	3.4	Crenshaw et al (1971)
Clay	2512	0.64	435	17.3	3.0	Crenshaw et al (1971)
Sand	5269	0.48	386	7.3	2.7	Crenshaw et al (1971)
Sand	5100	0.49	230	4.5	2.7	Crenshaw et al (1971)
Sand	5172	0.67	429	8.3	3.0	Crenshaw et al (1971)
Sand	215	0.35	30	14.0	2.5	Turnage (1982)
Sand	426	1.72	105	24.6	4.6	Turnage (1982)
Sand	450	0.76	70	15.6	3.1	Turnage (1982)
Sand	442	0.26	21	4.8	2.4	Turnage (1982)
Sand	458	0.94	60	13.1	3.4	Turnage (1982)
Sand	455	0.3	18	4.0	2.5	Turnage (1982)
Sand	455	0.04	8	1.8	2.1	Turnage (1982)
Sand	864	0.88	74	8.6	3.3	Turnage (1982)
Sand	863	0.18	35	4.1	2.3	Turnage (1982)
Sand	892	0.08	39	4.4	2.1	Turnage (1982)
Clay	876	1.72	198	22.6	4.6	Turnage (1982)
Clay	903	1.02	109	12.1	3.5	Turnage (1982)
Clay	884	0.13	25	2.8	2.2	Turnage (1982)

Notes:

1. Crenshaw Data:
   Tire Size = 29 x 11.10, Inflation Pressures = 30 - 70 psi
2. Turnage Data:
   Tire Sizes = 4.00 - 7 to 900 - 14; Inflation Pressures = 7 - 48 psi
3. Est. Rolling Resistance Values Computed from Egn. (6)
4. Meas. Rolling Resistance is the ratio of Tour Force to Tire load expressed as a percentage

TABLE 4-8

Rolling Resistance for Various Types of Road Surface

Type of Surface	Rolling Resistance (%)	Reference
Cement, asphalt, soil cement	2	Kaufman & Ault (1977)
Hard-packed gravel, cinders, or crushed rock	3	Kaufman & Ault (1977)
Moderately packed gravel, cinders, or crushed rock	5	Kaufman & Ault (1977)
Unmaintained loose earth	7.5	Kaufman & Ault (1977)
Loose gravel and muddy rutted material	10-20	Kaufman & Ault (1977)
In-situ clay till	4-6.7	Monenco (1983)
Compacted gravel	2-2.7	Monenco (1983)
Compacted clay-gravel	3.9	Monenco (1983)
Subsoil stockpile	4.4-8.3	Monenco (1983)
Compacted clay till	4.1	Monenco (1983)
Subsoil on mine spoil	7.3	Monenco (1983)
Asphalt	0.8-1.5	Johnson (1989)
Crushed limestone	3.4-4.2	Dionne (1987)
In-situ benonitic clay shale	7-13	Dionne (1987)
Loose snow	4.5	Caterpillar (1988)
Packed snow	2.5	Caterpillar (1988)
Concrete & asphalt	1.5*	Euclid (undated)
Smooth, hard, dry dirt and gravel, well maintained	2*	Euclid (undated)
Soft unplowed dirt, poorly maintained	4*	Euclid (undated)
Wet, muddy surface on firm base	4*	Euclid (undated)
Soft, plowed dirt or unpacted dirt fills	8*	Euclid (undated)
Loose sand and gravel	10*	Euclid (undated)
Deeply rutted or soft spongy base	16*	Euclid (undated)

* add 1.5% for every inch of tire penetration

TABEL 4-9

Advantages and Disadvantages of Various Road Surface Materials

Material	Advantages	Disadvantages
Asphaltic Concrete	o High coefficient of Adhesion o Minimizes dust problems o Smooth, stable surface o Low rolling resistance o Low maintenance cost o High vehicle speeds o Low Deformation underload	o Ices easily in cold weather o Needs base course with CBR - 80+ o High construction cost o Specialized construction o Impractical for tracked vehicles
Compacted Gravel & Crushed Rock	o Relatively smooth, stable surface o Relatively low construction cost o Low deformation underload o Ease of construction o Low rolling resistance	o Frequent maintenance required o Source material may require screening/crushing o Dust problems in dry weather o Erodable if flooded o Potential frost action (fines >10%)
Stabilized Earth	o Can decrease sub-ease thickness o Stabilize weak subgrade	o Not suitable as surface course
Rollcrete	o High coefficient of adhestion o Very low rolling resistance o Minimizes dust problems o Smooth, stable surface o Very low maintenance costs o High vehicle speeds o Very low deformation underload	o High construction cost o Impractical for tracked vehicles

TABLE 4-10

Critical Roadfill Thickness for Loaded Trucks
(after SHUKLA et al, 1989)

Hauler Capacity (tonnes)	Total Fill Thickness (cm)	Equivalent Wheel Load For Loaded Truck (kg)
35	90	17,100
50	105	26,009
85	140	42,500
120	150	60,600
170	180	80,500

TABLE 4-11

Recommended Grading for Granular Surface Course

ASTM Sieve Size	% by Weight Passing
3 in.	100
1 1/2 in.	70 - 100
1 in.	55 - 88
3/8 in.	40 - 70
#4	30 - 55
#10	22 - 42
#200	5 - 10

TABLE 4-12

Summary of Soil Improvement Methods
(after MITCHELL & KATTI, 1981)

	METHOD	PRINCIPLE	MOST SUITABLE SOIL CONDITIONS/ TYPES	MAXIMUM EFFECTIVE TREATMENT DEPTH	SPECIAL MATERIALS REQUIRED	SPECIAL EQUIPMENT REQUIRED	PROPERTIES OF TREATED MATERIAL	SPECIAL ADVANTAGES AND LIMITATIONS	RELATIVE COST
IN-SITU DEEP COMPACTION OF COHESIONLESS SOILS	BLASTING	Shock waves and vibrations cause liquefaction and displacement, with settlement to higher density	Saturated, clean sands; partly saturated sands and silts (collapsible loess) after flooding	>30 m	Explosives, backfill to plug drill holes, hole casings	Jetting or drilling machine	Can obtain relative densities to 70-80%; may get variable density; time-dependent strength gain	Rapid, inexpensive, can treat any size areas; variable properties, no improvement near surface, dangerous	Low
	VIBRATORY PROBE	Densification by vibration; liquefaction induced settlement under overburden	Saturated or dry clean sand	20 m (Ineffective above 3-4 m depth)	None	Vibratory pile driver and 750 mm dia. open steel pipe	Can obtain relative densities of up to 80%. Ineffective in some sands	Rapid, simple, good underwater; soft underlayers may damp vibrations, difficult to penetrate, stiff overlayers, not good in partly saturated soils	Moderate
	VIBRO-COMPACTION	Densification by vibration and compaction of backfill material	Cohesionless soils with less than 20% fines	30 m	Granular backfill, water supply	Vibroflot, crane, pumps	Can obtain high relative densities, good uniformity	Useful in saturated and partly saturated soils, uniformity	Moderate
	COMPACTION PILES	Densification by displacement of pile volume and by vibration during driving	Loose sandy soils; partly saturated clayey soils; loess	>20 m	Pile material (often sand or soil plus cement mixture)	Pile driver, special sand pile equipment	Can obtain high densities, good uniformity	Useful in soils with fines, uniform compaction, easy to check results; slow, limited improvement in upper 1-2 m	Moderate to high
	HEAVY TAMPING (Dynamic consolidation)	Repeated application of high intensity impacts at surface	Cohesionless soils, waste fills, partly saturated soils	30 m (?)	None	Tampers of up to 200 tons, high capacity crane	Can obtain good improvement and reasonable uniformity	Simple, rapid, suitable for some soils with fines; usable above and below water; requires control, must be away from existing structures	Low

TABLE 4-12 (Cont'd)

Summary of Soil Improvement Methods
(after MITCHELL & KATTI, 1981)

	METHOD	PRINCIPLE	MOST SUITABLE SOIL CONDITIONS/ TYPES	MAXIMUM EFFECTIVE TREATMENT DEPTH	SPECIAL MATERIALS REQUIRED	SPECIAL EQUIPMENT REQUIRED	PROPERTIES OF TREATED MATERIAL	SPECIAL ADVANTAGES AND LIMITATIONS	RELATIVE COST
PRECOMPRESSION	PRELOADING	Load is applied sufficiently in advance of construction so that compression of soft soils is completed prior to development of the site	Normally consolidated soft clays, silts, organic deposits, completed sanitary landfills	----	Earth fill or other material for loading the site; sand or gravel for drainage blanket	Earth moving equipment; large water tanks or vacuum drainage systems sometimes used; settlement markers, piezometers	Reduced water content and void ratio, increased strength	Easy, theory well developed, uniformity; requires long time (vertical drains can be used to reduce consolidation time)	Low (Moderate if vertical drains are required)
	SURCHARGE FILLS	Fill in excess of that required permanently is applied to achieve a given amount of settlement in a shorter time; excess fill then removed	Normally consolidated soft clays, silts, organic deposits, completed sanitary landfills	----	Earth fill or other material for loading the site; sand or gravel for drainage blanket	Earth moving equipment; settlement markers, piezometers	Reduced water content, void ratio and compressibility; increased strength	Faster than preloading without surcharge, theory well developed; extra material handling; can use vertical drains to reduce consolidation time	Moderate
	ELECTRO-OSMOSIS	DC current causes water flow from anode towards cathode where it is removed	Normally consolidated silts and silty clays		Anodes (usually rebars or aluminum), cathodes (well points or rebars)	DC power supply, wiring, metering systems	Reduced water content and compressibility, increased strength, electrochemical hardening	No fill loading required, can use in confined area, relatively fast; non-uniform properties between electrodes, no good in highly conductive soils	High
ADMIXTURES	REMOVE AND REPLACE	Foundation soil excavated, improved by drying or admixture, and recompacted	Inorganic soils	10 m (?)	Admixture stabilizers	Excavating, mixing, and compaction equipment, dewatering system	Increased strength and stiffness, reduced compressibility	Uniform, controlled foundation soil when replaced; may require large area dewatering	High
	STRUCTURAL FILLS	Structural fill distributes loads to underlying soft soils	Use over soft clays or organic soils, marsh deposits	----	Sand, gravel, flyash, bottom ash, slag, expanded aggregate, clam shell or oyster shell, incinerator ash	Mixing and compaction equipment	Soft subgrade protected by structural load-bearing fill	High strength, good load distribution to underlying soft soils	Low to high
	MIX-IN-PLACE PILES AND WALLS	Lime, cement, or asphalt introduced through rotating auger or special in-place mixer	All soft or loose inorganic soils	>20 m	Cement, lime, asphalt, or chemical stabilizer	Drill rig, rotary cutting and mixing head, additive proportioning equipment	Solidified soil piles or walls of relatively high strength	Uses native soil, reduced lateral support requirements during excavation; difficult quality control	Moderate to high

TABLE 4-12 (Cont'd)

Summary of Soil Improvement Methods
(after MITCHELL & KATTI, 1981)

	METHOD	PRINCIPLE	MOST SUITABLE SOIL CONDITIONS/ TYPES	MAXIMUM EFFECTIVE TREATMENT DEPTH	SPECIAL MATERIALS REQUIRED	SPECIAL EQUIPMENT REQUIRED	PROPERTIES OF TREATED MATERIAL	SPECIAL ADVANTAGES AND LIMITATIONS	RELATIVE COST
THERMAL	HEATING	Drying at low temperatures; alteration of clays at intermediate temperatures (400-600°C); fusion at high temperatures (>1000°C)	Fine-grained soils, especially partly saturated clays and silts, loess	15 m	Fuel	Fuel tanks, burners, blowers	Reduced water content, plasticity, water sensitivity; increased strength	Can obtain irreversible improvements in properties; can introduce stabilizers with hot gases	High
	FREEZING	Freeze soft, wet ground to increase its strength and stiffness	All soils	Several m	Refrigerant	Refrigeration system	Increased strength and stiffness; reduced permeability	No good in flowing ground water, temporary	High
REINFORCEMENT	VIBRO-REPLACEMENT STONE AND SAND COLUMNS	Hole jetted into soft, fine-grained soil and backfilled with densely compacted gravel or sand	Soft clays and alluvial deposits	20 m	Gravel or crushed rock backfill	Vibroflot, crane or vibrocat, water	Increased bearing capacity, reduced settlements	Faster than precompression, avoids dewatering required for remove and replace; limited bearing capacity	Moderate to high
	ROOT PILES, SOIL NAILING	Inclusions used to carry tension, shear, compression	All soils	?	Reinforcing bars, cement grout	Drilling and grouting equipment	Reinforced zone behaves as a coherent mass	In-situ reinforcement for soils that can't be grouted or mixed-in-place with admixtures	Moderate to high
	STRIPS AND MEMBRANES	Horizontal tensile strips, membranes buried in soil under embankments, gravel base courses and footings	Cohesionless soils	Can construct earth structures to heights of several tens of m	Metal or plastic strips, geotextiles	Excavating, earth handling, and compaction equipment	Self-supporting earth structures, increased bearing capacity, reduced deformations	Economical, earth structures coherent, can tolerate deformations; increased allowable bearing pressure	Low to moderate

TABLE 4-12 (Cont'd)

Summary of Soil Improvement Methods
(after MITCHELL & KATTI, 1981)

	METHOD	PRINCIPLE	MOST SUITABLE SOIL CONDITIONS/ TYPES	MAXIMUM EFFECTIVE TREATMENT DEPTH	SPECIAL MATERIALS REQUIRED	SPECIAL EQUIPMENT REQUIRED	PROPERTIES OF TREATED MATERIAL	SPECIAL ADVANTAGES AND LIMITATIONS	RELATIVE COST
INJECTION AND GROUTING	PARTICULATE GROUTING	Penetration grouting-fill soil pores with soil, cement, and/or clay	Medium to coarse sand and gravel	Unlimited	Grout, water	Mixers, tanks, pumps, hoses	Impervious, high strength with cement grout, eliminate liquefaction danger	Low cost grouts, high strength; limited to coarse-grained soils, hard to evaluate	Lowest of the grout systems
	CHEMICAL GROUTING	Solutions of two or more chemicals react in soil pores to form a gel or a solid precipitate	Medium silts and coarser	Unlimited	Grout, water	Mixers, tanks, pumps, hoses	Impervious, low to high strength, eliminate liquefaction danger	Low viscosity, controllable gel time, good water shut-off; high cost, hard to evaluate	High to very high
	PRESSURE INJECTED LIME	Lime slurry injected to shallow depths under high pressure	Expansive clays	Unlimited, but 2-3 m usual	Lime, water, surfactant	Slurry tanks, agitators, pumps, hoses	Lime encapsulated zones formed by channels resulting from cracks, root holes, hydraulic fracture	Only effective in narrow range of soil conditions	Competitive with other solutions to expansive soil problems
	DISPLACEMENT GROUT	Highly viscous grout acts as radial hydraulic jack when pumped in under high pressure	Soft, fine-grained soils; foundation soils with large voids or cavities	Unlimited, but a few m usual	Soil, cement water	Batching equipment, high pressure pumps, hoses	Grout bulbs within compressed soil matrix	Good for correction of differential settlements, filling large voids; careful control required	Low material, high injection
	ELECTRO-KINETIC INJECTION	Stabilizing chemicals moved into soil by electro-osmosis or colloids into pores by electrophoresis	Saturated silts, silty clays (clean sands in case of colloid injection)	Unknown	Chemical stabilizer colloidal void fillers	DC power supply, anodes, cathodes	Increased strength, reduced compressibility, reduced liquefaction potential	Existing soil and structures not subjected to high pressures; no good in soil with high conductivity	Expensive
	JET GROUTING	High speed jets at depth excavate, inject, and mix stabilizer with soil to form columns or panels	Sands, silts, clays		Water, stabilizing chemicals	Special jet nozzle, pumps, pipes and hoses	Solidified columns and walls	Useful in soils that can't be permeation grouted, precision in locating treated zones	

TABLE 4-13

Properties of Typical Tensar Geogrids

Property	Test Method	Units	Biaxial Geogrid Type			
			SS0	SS1	SS2	SS3
Interlock						
o aperture size[1] (nom)	I.D. Calipered[2]					
o MD		in	1.3	1.3	1.3	2.5
o CMD		in	1.0	1.0	1.0	1.8
o open area (min)	COE Method[3]	%	70	70	70	75
o thickness (nom)	ASTM D 1777-64					
o ribs		in	0.03	0.03	0.05	0.049
o junctions		in	0.09	0.11	0.16	0.17
Reinforcement						
o flexural rigidity (min)	ASTM D1388-64[4]					
o MD		mg cm	150,000	250,000	750,000	450,000
o CMD		mg-cm	-- --	1,000,000	--	
o tensile Modulus (min)	GRI GGI-87[5]					
o MD		lb/ft	12,500	14,000	18,500	15,000
o CMD		lb/ft	-- --	30,500	--	
o junction strength (min)	GRI GG2-87[6]					
o MD		lb/ft	600750	1,050	960	
o CMD		lb/ft	-- --	1,890	--	
o junction efficiency (min)	GRI GG2-87[6]	%	90 90	90	90	

TABLE 4-13 (Cont'd)

Properties of Typical Tensar Geogrids

Property	Test Method	Units	Biaxial Geogrid Type			
			SS0	SS1	SS2	SS3
Material						
o polypropylene (min)	ASTM D4101 Group 1/Class 1/Grade 2	%	97	98	98	98
o carbon black (min)	ASTM 4218	%	2.0	0.5	0.5	0.5
Dimensions						
o roll length		ft	164	164	164	164
o roll width		ft	-	9.8 & 13.1	-	-
o roll weight		lb	58 & 78	71 & 95	102 & 135	82 & 109

Notes:

1 MD dimension is along roll length. CMD dimension is across roll width.

2 Maximum inside dimension in each principal direction measured by calipers.

3 Percent open area measured without magnification by Corps of Engineer method as specified in CW 02215 Civil Works Construction Guide, November 1977.

4 ASTM D 1388-64 modified to account for wide specimen testing as described in Tensar test method TTM-5.0 "Stiffness of Geosynthetics".

5 Secant modulus at 2% elongation measured by Geosynthetic Research Institute test method GG1-87 "Geogrid Tensile Strength". No offset allowances are made in calculating secant modulus.

6 Geogrid junction strength and junction efficiency measured by Geosynthetic Research Institute test method GG2-87 "Geogrid Junction Strength".

TABLE 4-14

Guide for Estimating Subgrade Soil Strengths (Fine-Grained Soils)

C_u Shear Strength (psf) (psi)	SPT (blows/ft)	Cone Penetrometer	CBR	Estimated Consistency
< 250 (1.7)	< 2	< .24	< 0.4	Very soft (extruded between fingers when squeezed)
250-500 (1.7-3.5)	2-4	24-48	0.4-0.8	Soft (molded by light finger pressure)
500-1000 (3.5-6.9)	4-8	48-96	0.8-1.6	Medium (molded by strong finger pressure)
1000-2000 (6.9-13.9)	8-15	96-192	1.6-3.2	Stiff (readily indented by thumbs, but penetrated with great effort)
2000-4000 (13.9-27.7)	15-30	192-384	3.2-6.4	Very stiff readily indented by thumb nail)
> 4000 (27.7)	> 30	> 384	> 6.4	Hard (indented with difficulty by thumb nail)

(After Portland Cement Association, E.I. DuPort literature and McCarthy, David F., "Essentials of Soul Mechanics and Foundation, 1977).

TABLE 4-15

Guide for Estimating CBR by Soil Classification
(from Corps of Engineers)

Major (1)	Divisions (2)	Letter (3)	Name (4)	Value as Foundation When Not Subject to Frost Action (5)	Value as Base Directly Under Wearing Surface (6)	Potential Frost Action (7)	Compressibility and Expansion (8)	Drainage Characteristics (9)	Compaction Equipment (10)	Unit Dry Weight (pcf) (11)	Field CBR (12)	Subgrade Modulus (pci) (13)
Coarse-grained soils	Gravel and gravelly soils	GW	Gravel or sandy gravel, well graded	Excellent	Good	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment steel-wheeled roller	125-140	60-80	300 or more
		GP	Gravel or sandy gravel, poorly graded	Good to excellent	Poor to fair	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment, steel-wheeled roller	120-130	35-60	300 or more
		GU	Gravel or sandy gravel, uniformly graded	Good	Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equpment	115-125	25-50	300 or more
		GM	Silty gravel or silty sandy gravel	Good to excellent	Fair to good	Slight to medium	Very slight	Fair to poor	Rubber-tired equipment, sheepsfoot roller, close control of moisture	130-145	40-80	300 or more
		GC	Clayey gravel or clayey sandy gravel	Good	Poor	Slight to medium	Slight	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	120-140	20-40	200-300
	Sand and sandy soils	SW	Sand or gravelly sand, well graded	Good	Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	110-130	20-40	200-300
		SP	Sand or gravelly sand, poorly graded	Fair to good	Poor to not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	105-120	15-25	200-300
		SU	Sand or gravelly sand, uniformly graded	Fair to good	Not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	100-115	10-20	200-300
		SM	Silty sand or silty gravelly sand	Good	Poor	Slight to high	Very slight	Fair to poor	Rubber-tired equipment, sheepsfoot roller, close control of moisture	120-135	20-40	200-300
		SC	Clayey sand or clayey gravelly sand	Fair to good	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	105-130	10-20	200-300
Fine-grained soils	Low compressibility LL < 50	ML	Silts, sandy silts, gravelly silts, or diatomaceous soils	Fair to poor	Not suitable	Medium to very high	Slight to medium	Fair to poor	Rubber-tired equipment, sheepsfoot roller, close control of moisture	100-125	5-15	100-200
		CL	Lean clays, sandy clays, or gravelly clays	Fair to poor	Not suitable	Medium to high	Medium	Practically impervious	Rubber-tired equipment, sheepsfoot roller	100-125	5-15	100-200
		OL	Organic silts or lean organic clays	Poor	Not suitable	Medium to high	Medium to high	Poor	Rubber-tired equipment, sheepsfoot roller	90-105	4-8	100-200
	High compressibility LL > 50	MH	Micaceous clays or diatomaceous soils	Poor	Not suitable	Medium to very high	High	Fair to poor	Rubber-tired equipment, sheepsfoot roller	80-100	4-8	100-200
		CH	Fat clays	Poor to very poor	Not suitable	Medium	High	Practically impervious	Rubber-tired equipment, sheepsfoot roller	90-110	3-5	50-100
		OH	Fat organic clays	Poor to very poor	Not suitable	Medium	High	Practically impervious	Rubber-tired equipment, sheepsfoot roller	80-105	3-5	50-100
Peat and other fibrous organic soils		Pt	Peat, humus, muskeg	Not suitable	Not suitable	Slight	Very high	Fair to poor	Compaction not practical	50-80	-	-

TABLE 5-1

Typical Maintenance and Service Costs for Various Types of Equipment*

			Maintenance Cost ($/h)		
Equipment Type	Make	Model	Labour	Parts	Fuel, Oil & Grease Cost ($/h)
Backhoe	Caterpillar	235	12.00	6.00	7.00
Dozer	Caterpillar	D8L	10.00	17.00	11.50
Dozer	Caterpillar	D9L	10.00	21.00	14.50
Dozer	Caterpillar	D11N	10.00	28.00	23.50
F.E. Loader	Caterpillar	992C	8.50	11.00	20.00
Grader	Caterpillar	16G	8.50	11.50	7.00
Packer	Caterpillar	815C	7.50	6.50	3.50
Scraper	Caterpillar	637D	14.50	22.50	17.00
Truck	Caterpillar	769	9.00	11.00	7.50
Truck	Euclid	R85	19.50	21.50	15.00
Truck	Terex	34-11C	15.50	42.00	16.50
Truck	Terex	34-15C	28.00	56.00	30.00
Watertruck	Caterpillar	772	13.50	11.50	12.00

* from Monenco files

TABLE 5-2

Owning and Operating Costs for Caterpillar Off-Highway Trucks & Tractors*

Model	O&O Costs $/h		
	Moderate	Average	Severe
768C	36	47	71
769C	31	41	64
772B	47	61	96
773B	43	58	90
776B (est.)	54	79	126
777B (est.)	50	76	120
785	(insufficient data)		
789	(insufficient data)		

Notes:

1. Costs expressed in Canadian $ assuming 1 US$ = 1.2 Can $
2. Costs based on equipment fitted with:
   - Body liners on trucks
   - NOSPIN differential
   - Downshift inhibitor
   - Standard E-3 tires

* Data from Caterpillar Handbook, 19th Ed., Oct. 1988; p. 767.

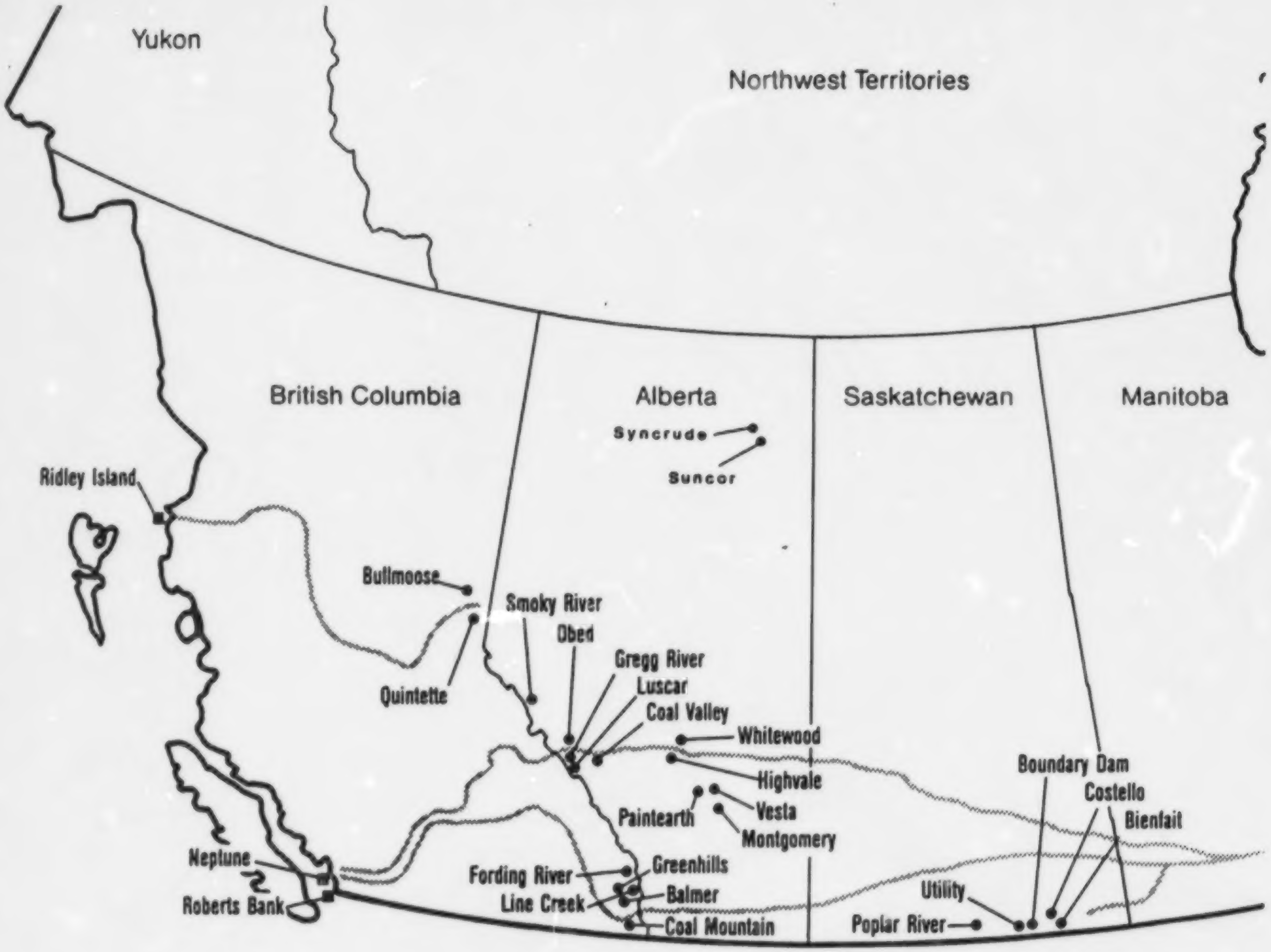

Yukon
Northwest Territories
British Columbia
Alberta
Saskatchewan
Manitoba
Syncrude
Suncor
Ridley Island
Bullmoose
Quintette
Smoky River
Obed
Gregg River
Luscar
Coal Valley
Whitewood
Highvale
Paintearth
Vesta
Montgomery
Neptune
Roberts Bank
Fording River
Line Creek
Greenhills
Balmer
Coal Mountain
Boundary Dam
Costello
Bienfait
Utility
Poplar River

Figure 2-1 Location of Surface Mines in Western Canada

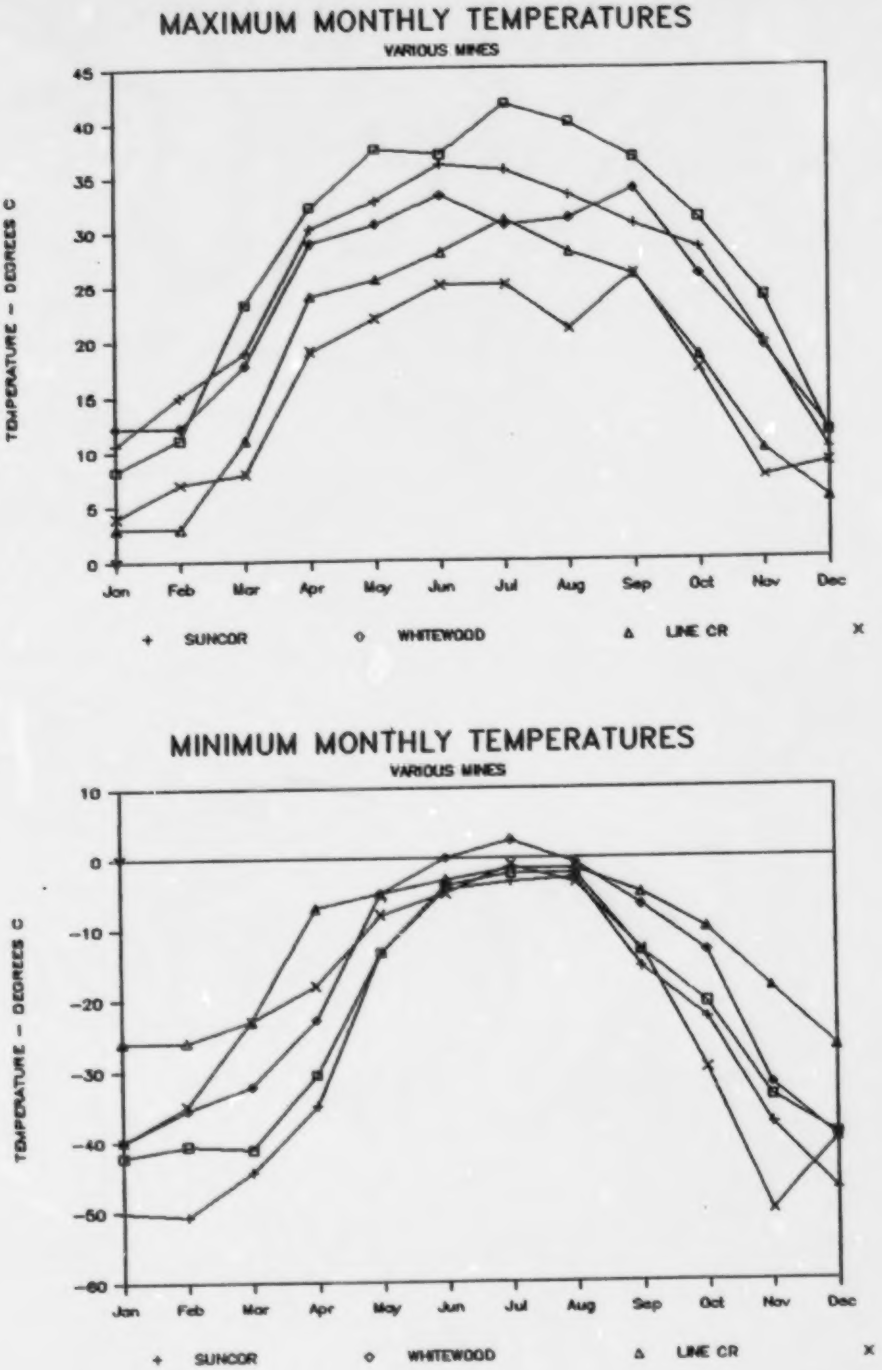


Figure 2-2 Extreme Temperature Variations at Western Mines

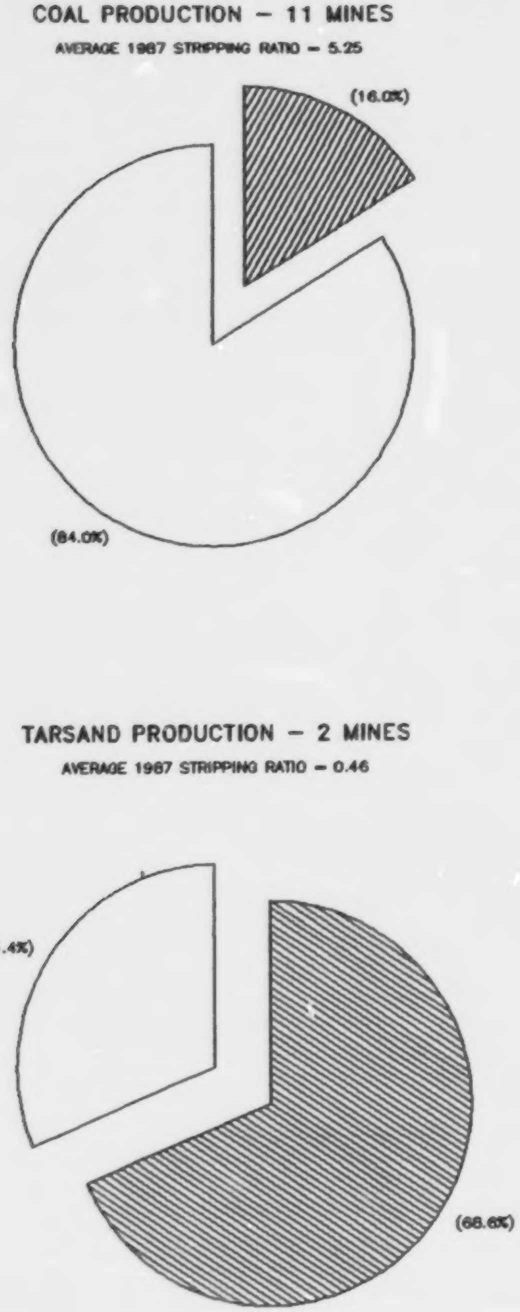


Figure 2-3 Aggregate Stripping Ratios for Coal & Tarsands Operations

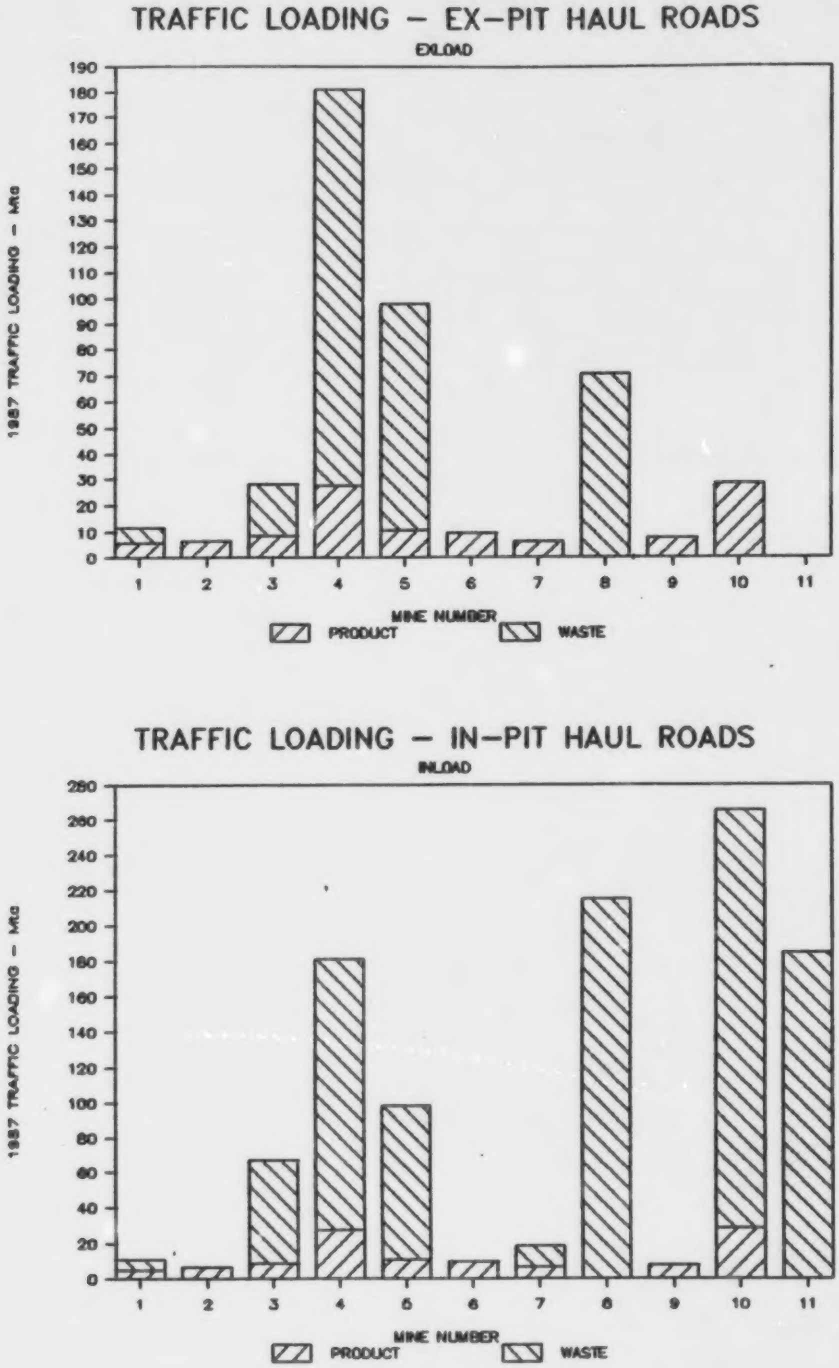


Figure 2-4   Variations in Haulroad Traffic Loading

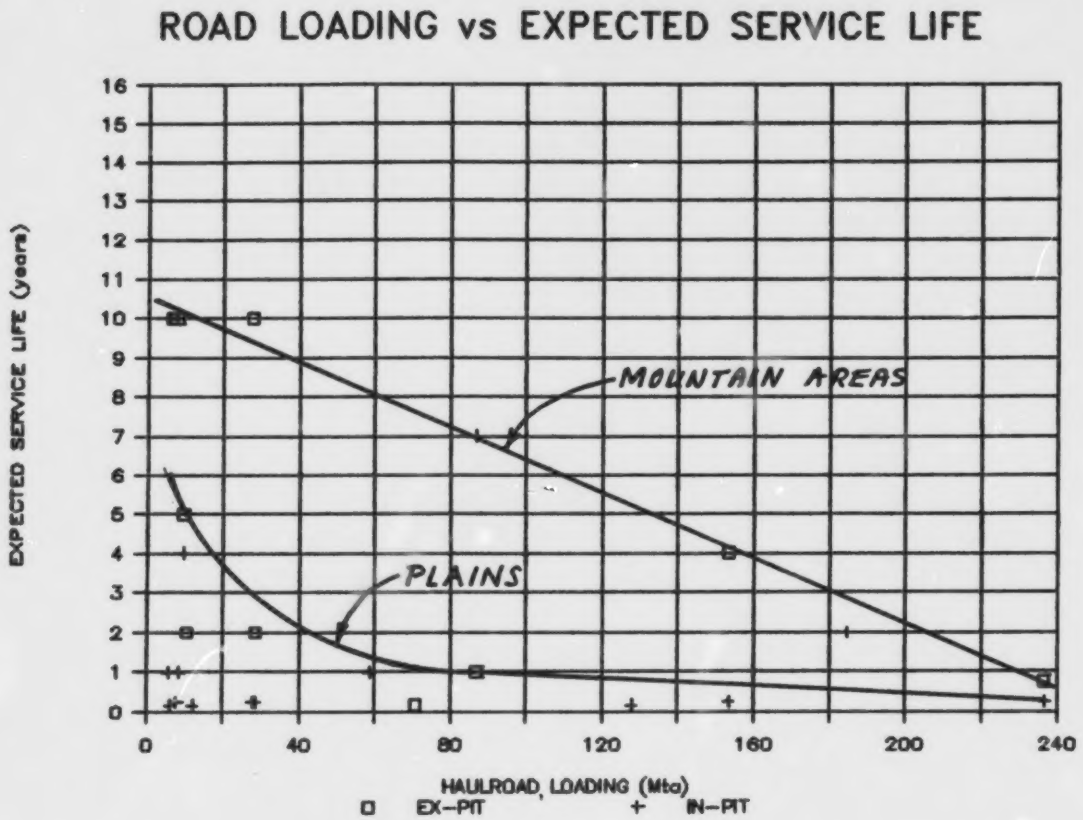


Figure 2-5 Road Loading vs. Expected Service Life

VISIBILITY

OF 33-15C TITAN HAULER OPERATOR

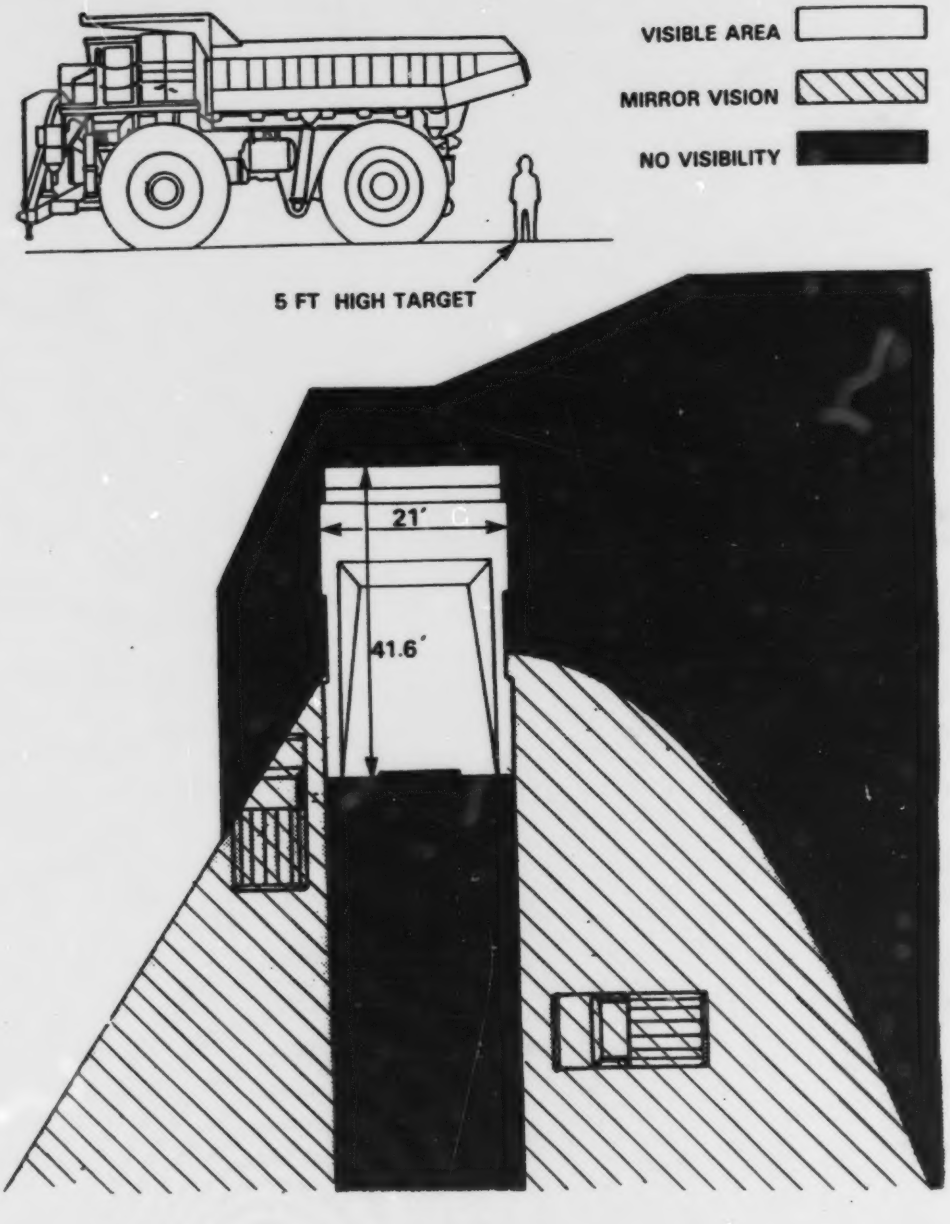
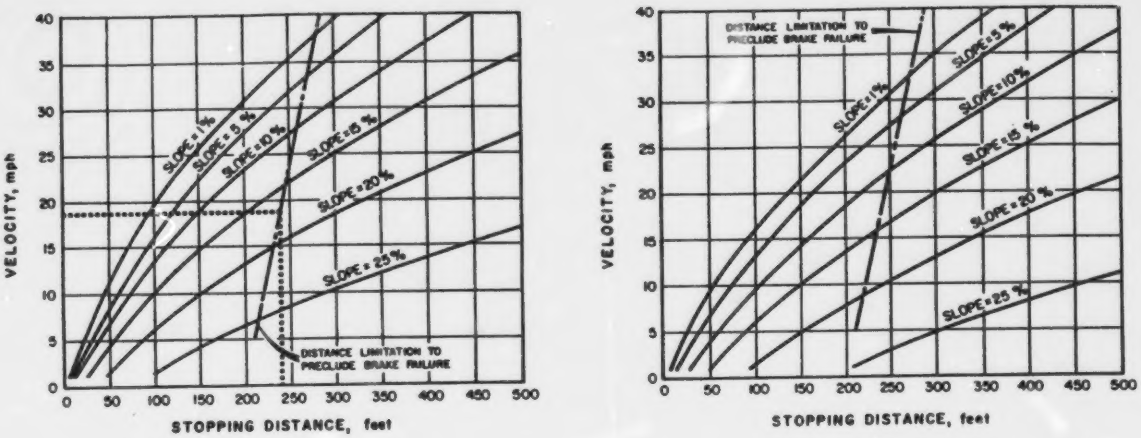
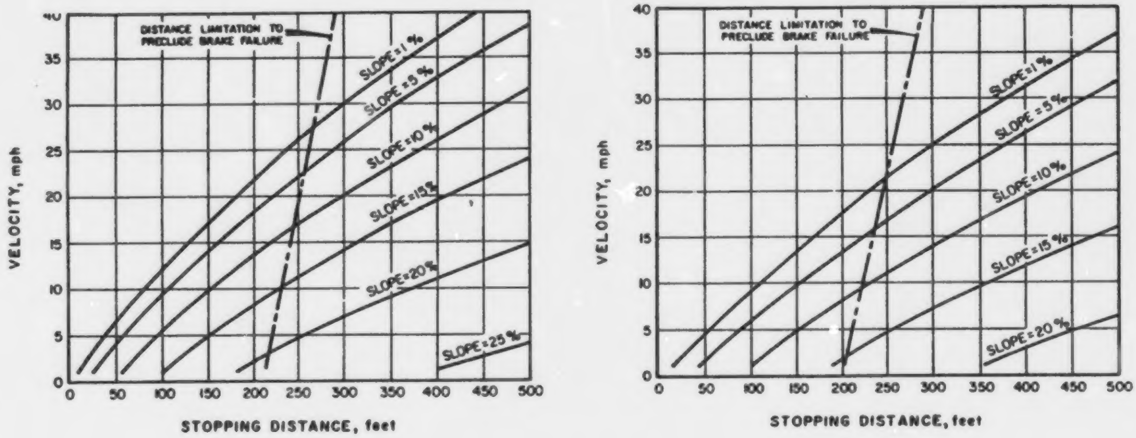

VISIBLE AREA
MIRROR VISION
NO VISIBILITY
5 FT HIGH TARGET
21'
41.6'

Figure 4-1   Visability of 33-15C Titan Hauler Operator



(a) Category 1 Vehicles

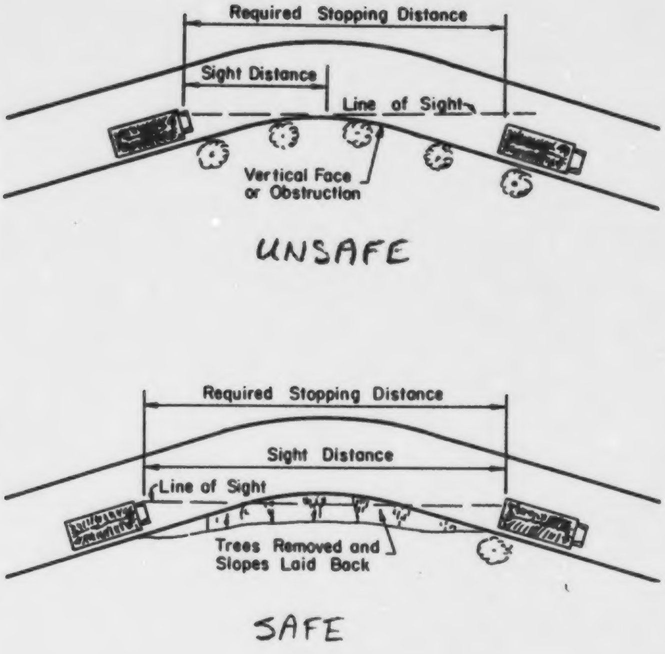
(b) Category 2 Vehicles



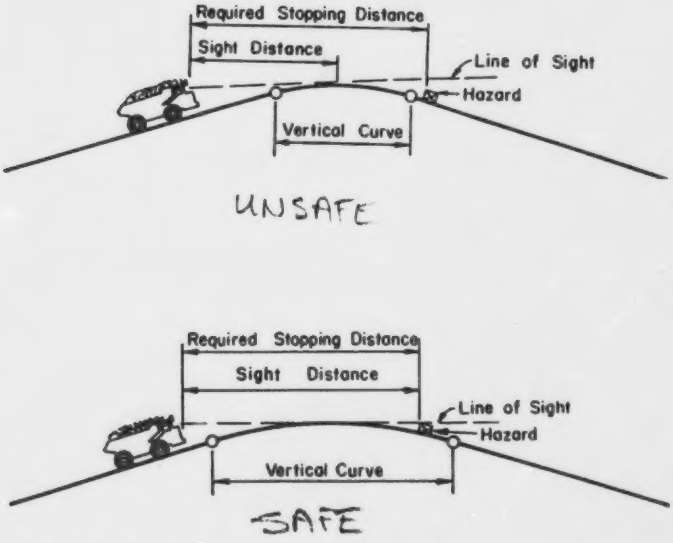
(c) Category 3 Vehicles

(d) Category 4 Vehicles

Figure 4-2 Stopping Distance Characteristics for Haulers of Various Weights


Required Stopping Distance
Sight Distance
Line of Sight
Vertical Face or Obstruction
UNSAFE
Required Stopping Distance
Sight Distance
Line of Sight
Trees Removed and Slopes Laid Back
SAFE

(a) HORIZONTAL CURVES


Required Stopping Distance
Sight Distance
Line of Sight
Hazard
Vertical Curve
UNSAFE
Required Stopping Distance
Sight Distance
Line of Sight
Hazard
Vertical Curve
SAFE

(b) VERTICAL CURVES

Figure 4-3 Sight Distance Diagrams for Horizontal and Vertical Curves

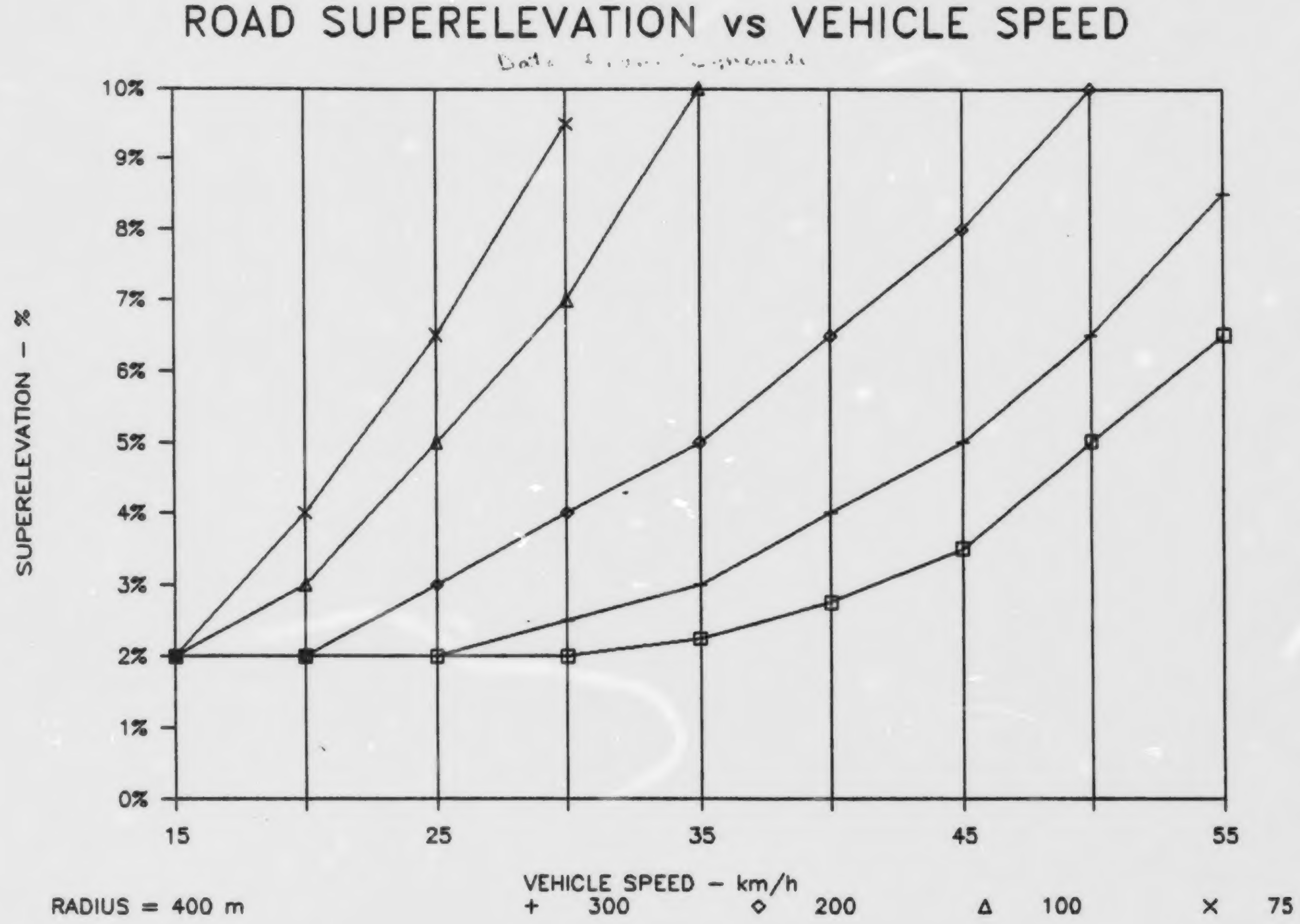
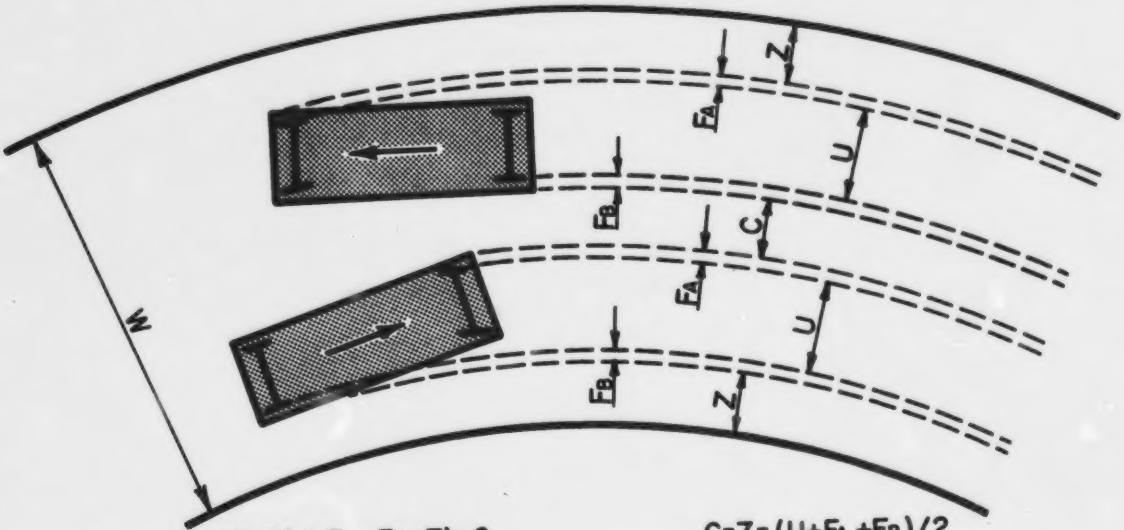


Figure 4-4 Road Superelevation vs. Vehicle Speed



$W=2(U+F_A+F_B+Z)+C$

$C=Z=(U+F_A+F_B)/2$

U = Track width of vehicle (center-to-center tires), feet

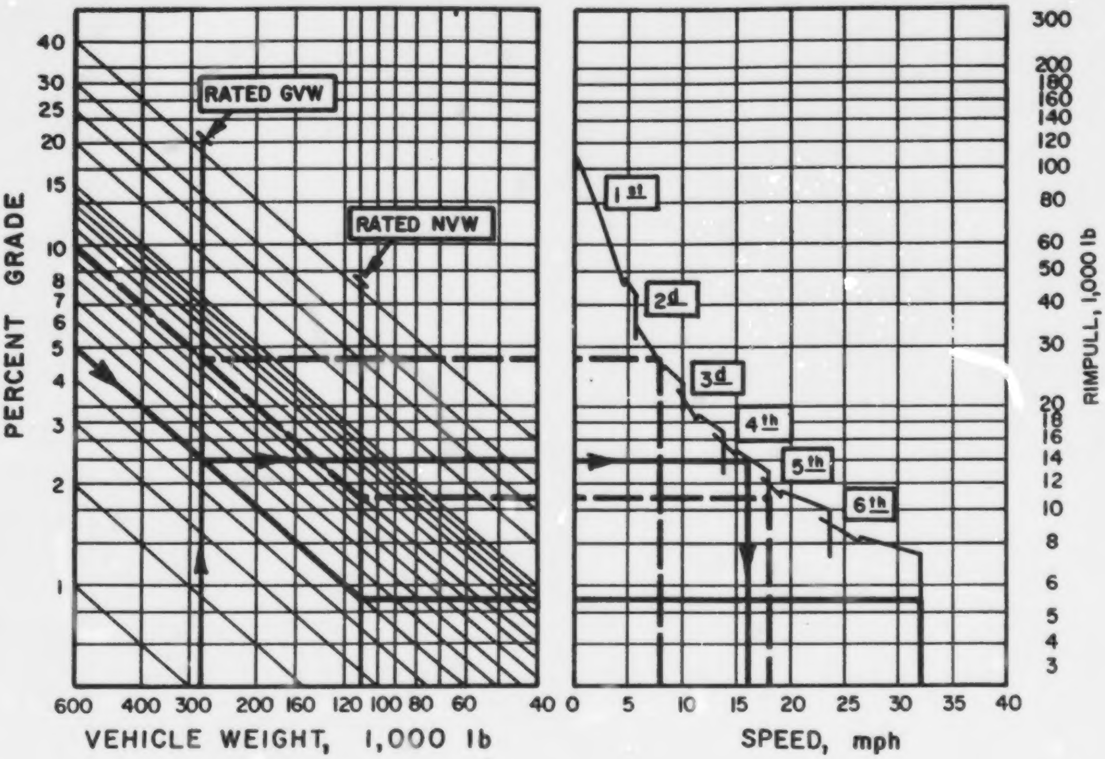
F_A = Width of front overhang, feet

F_B = Width of rear overhang, feet

C = Total lateral clearance

Z = Extra width allowance due to difficulty of driving on curves, feet

Figure 4-5 Procedure for Computing Road Width on Horizontal Curves



PROCEDURE

1. FIND VEHICLE WEIGHT ON LOWER LEFT HORIZONTAL SCALE
2. FIND SLANT LINE CORRESPONDING TO PERCENT GRADE ON VERTICAL SCALE
3. AT INTERSECTION BETWEEN VERTICAL WEIGHT LINE AND SLANT GRADE LINE, READ HORIZONTALLY TO INTERSECTION WITH PERFORMANCE CURVE
4. READ DOWN FOR VEHICLE SPEED

Figure 4-6 Vehicle Performance Chart - Ascending Grades

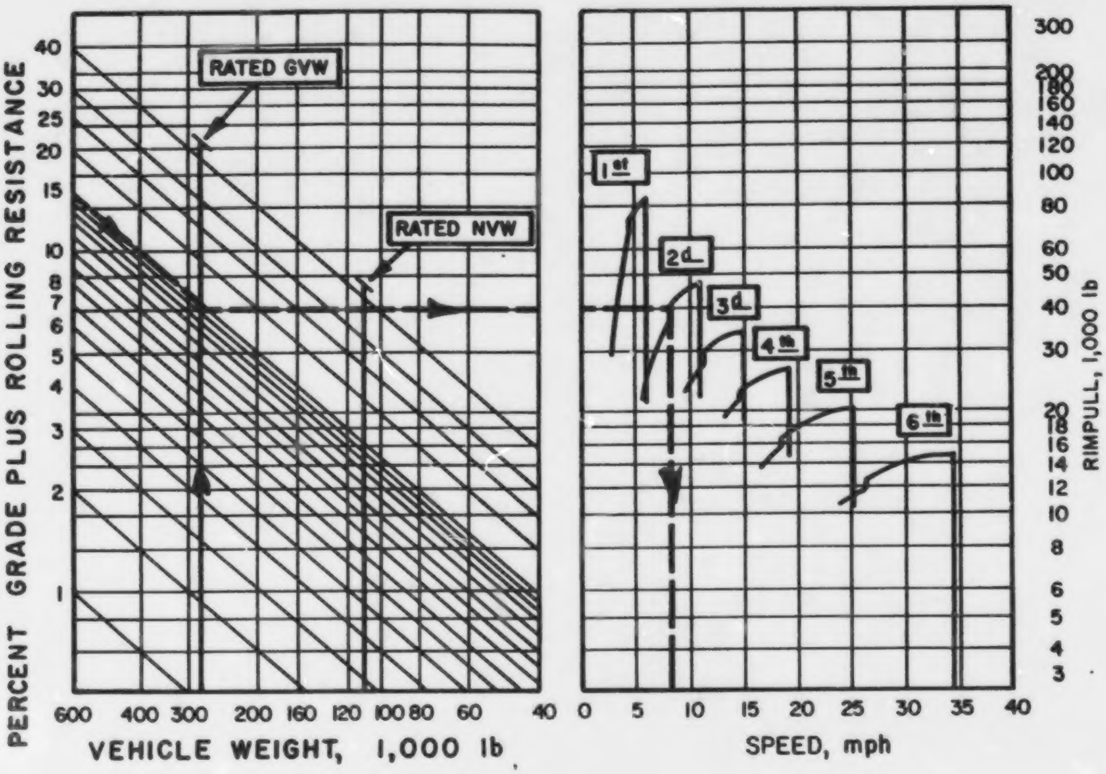


Figure 4-7 Vehicle Performance Chart - Descending Grades

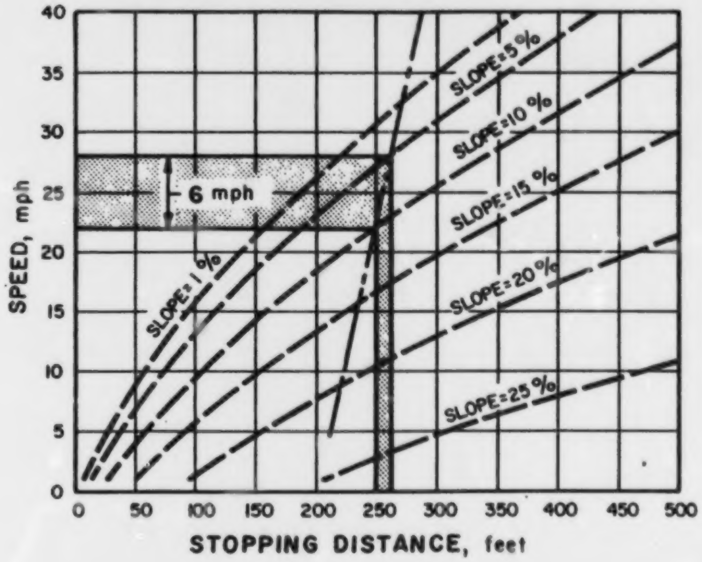


Figure 4-8 Effect of Grade Reduction on Stopping Distances

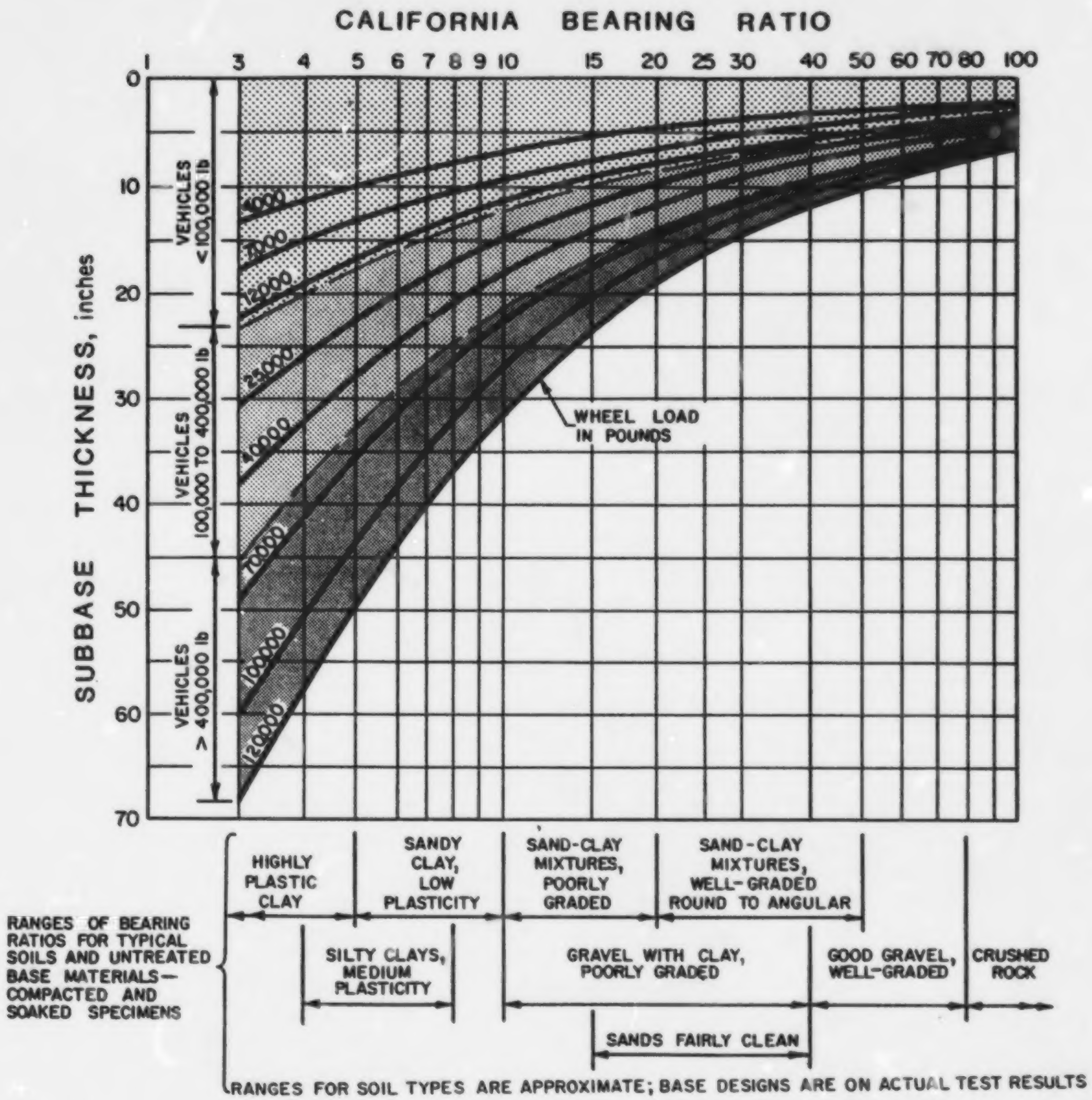


Figure 4-9 CBR Curves

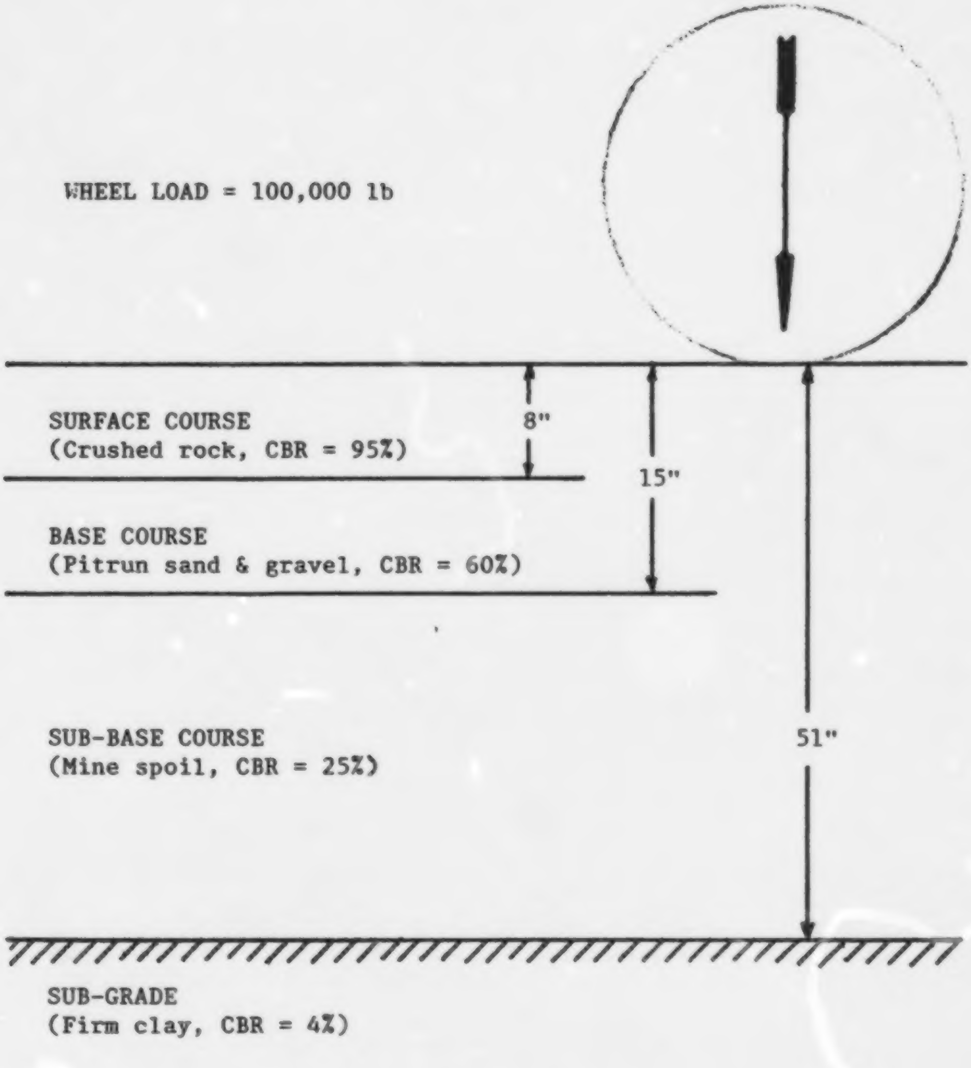

WHEEL LOAD = 100,000 lb
SURFACE COURSE
(Crushed rock, CBR = 95%)
8"
15"
BASE COURSE
(Pitrun sand & gravel, CBR = 60%)
SUB-BASE COURSE
(Mine spoil, CBR = 25%)
51"
SUB-GRADE
(Firm clay, CBR = 4%)

Figure 4-10 Example of CBR Method

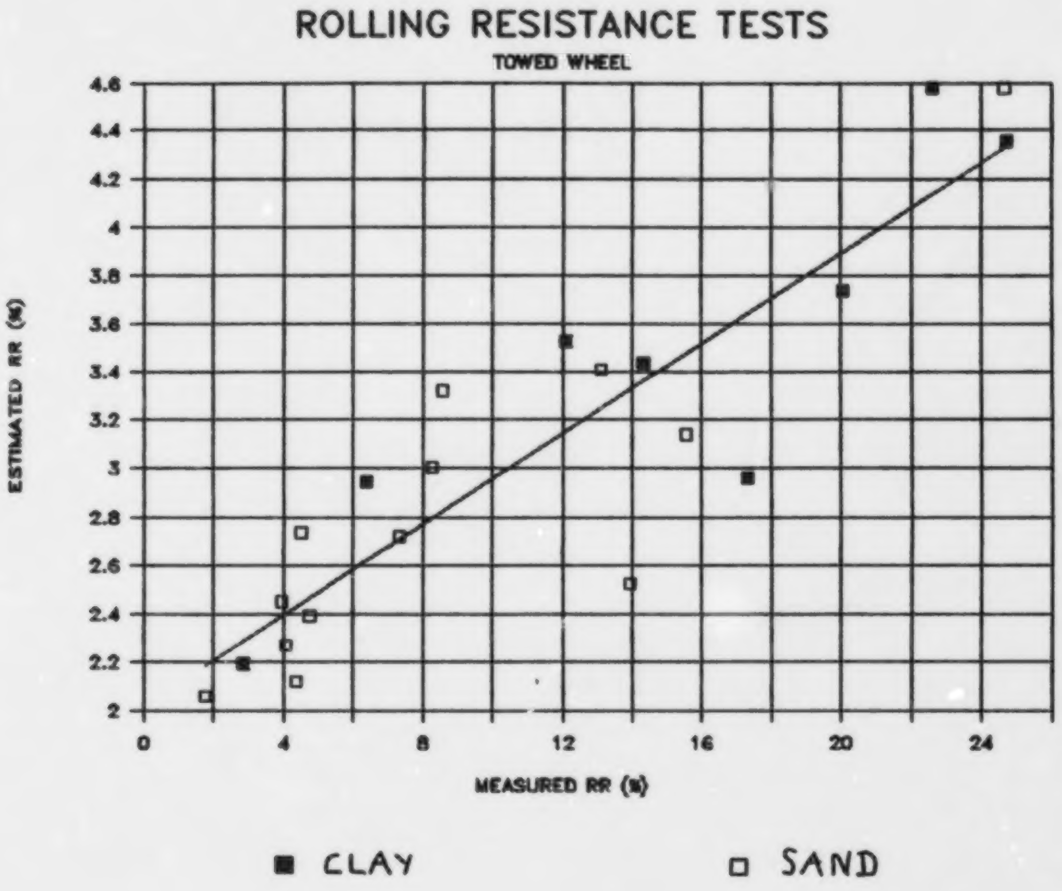


Figure 4-11 Rolling Resistance Tests - Towed Wheel

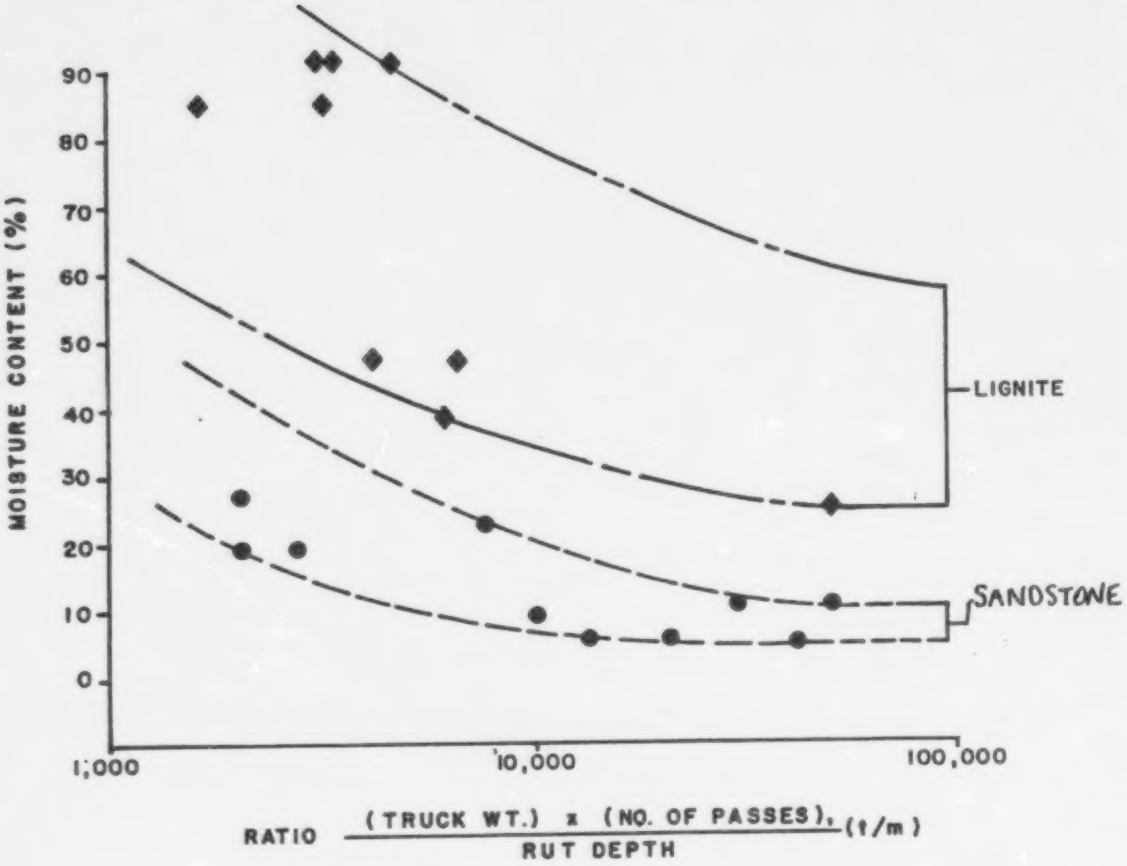


Figure 4-12 Moisture Content vs. Trafficability

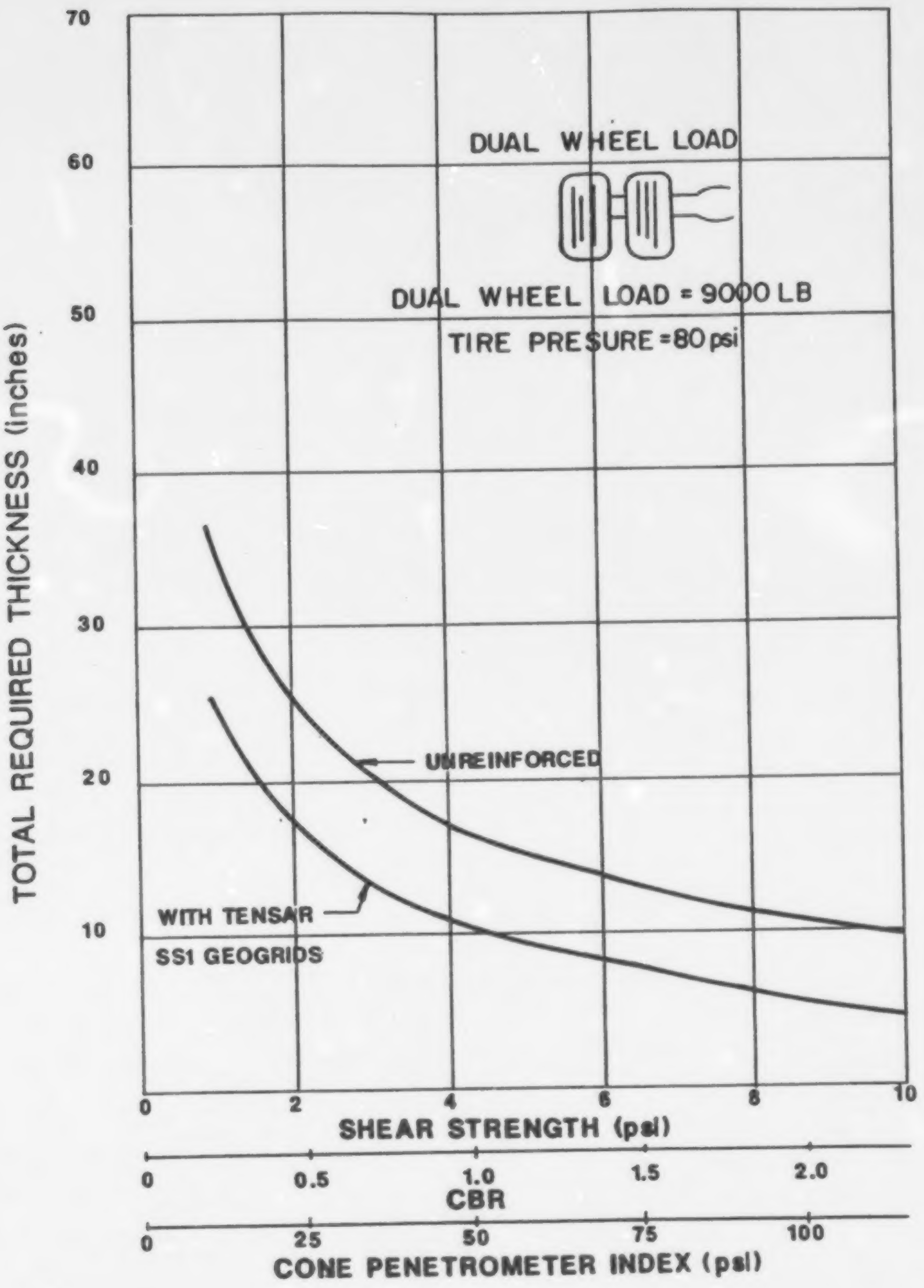


Figure 4-13 Thickness Requirements for 9,000 lb Dual Wheel Loads

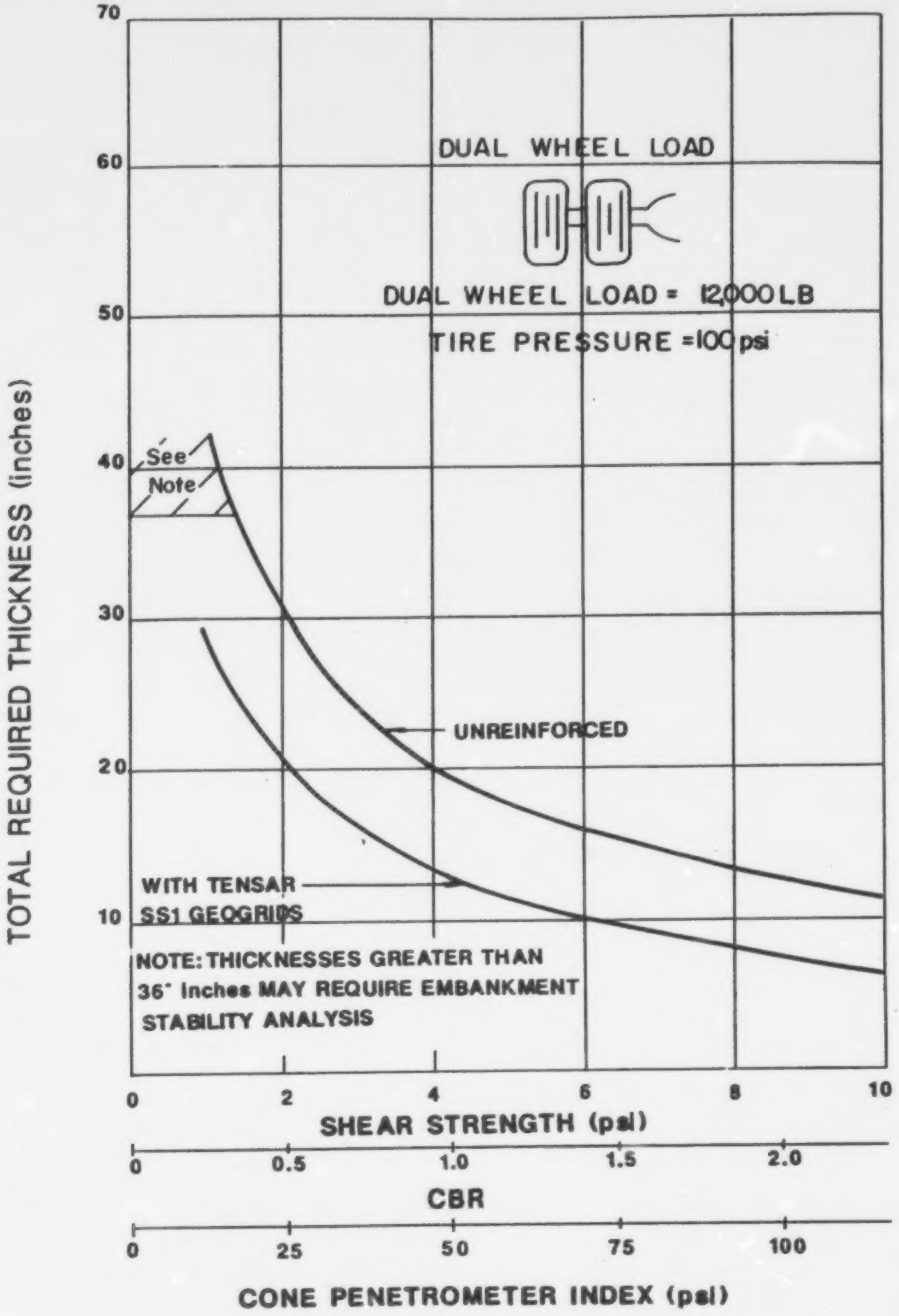


Figure 4-14 Thickness Requirements for 12,000 lb Dual Wheel Loads

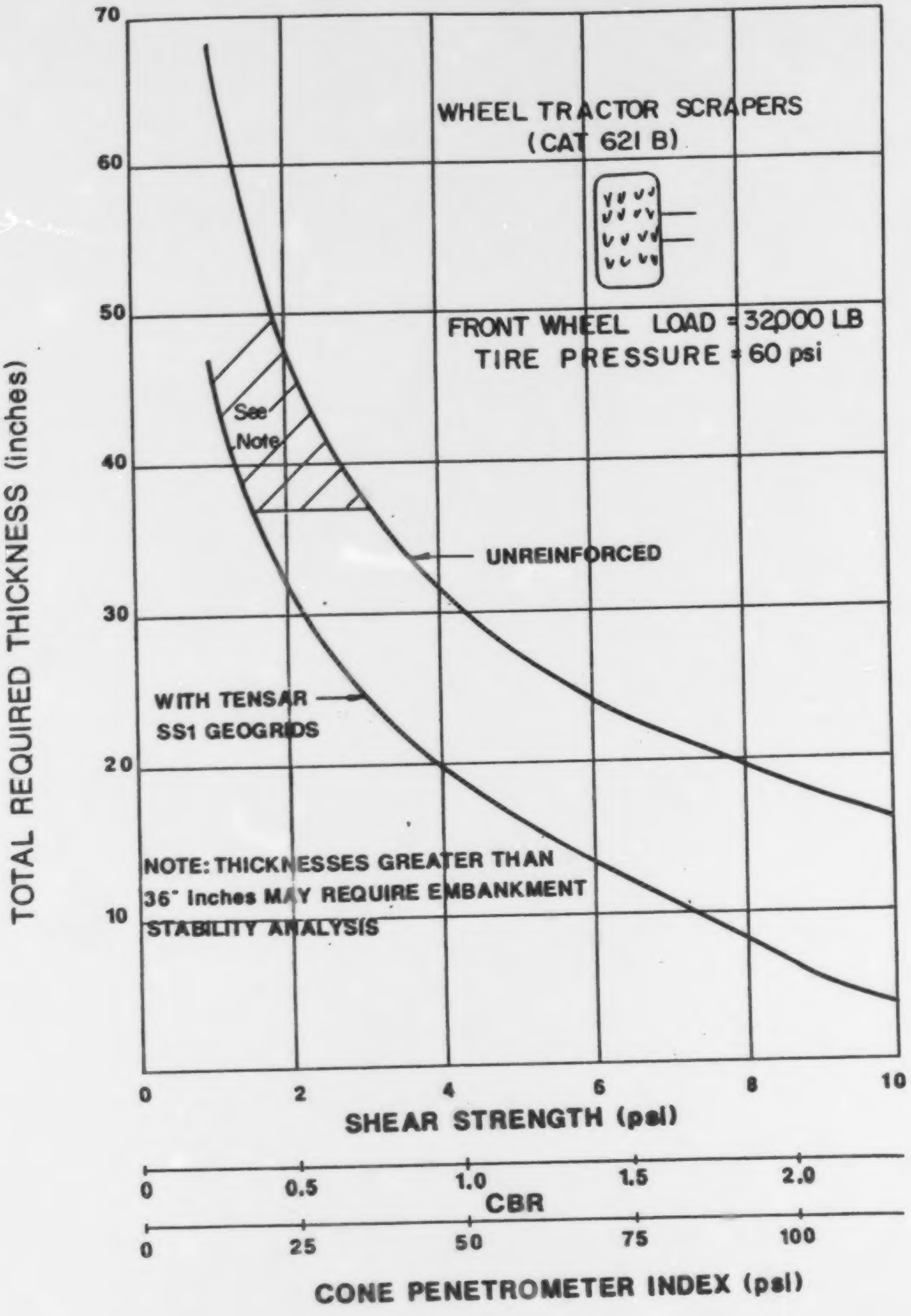


Figure 4-15 Thickness Requirements for 32,000 lb Single Wheel Loads

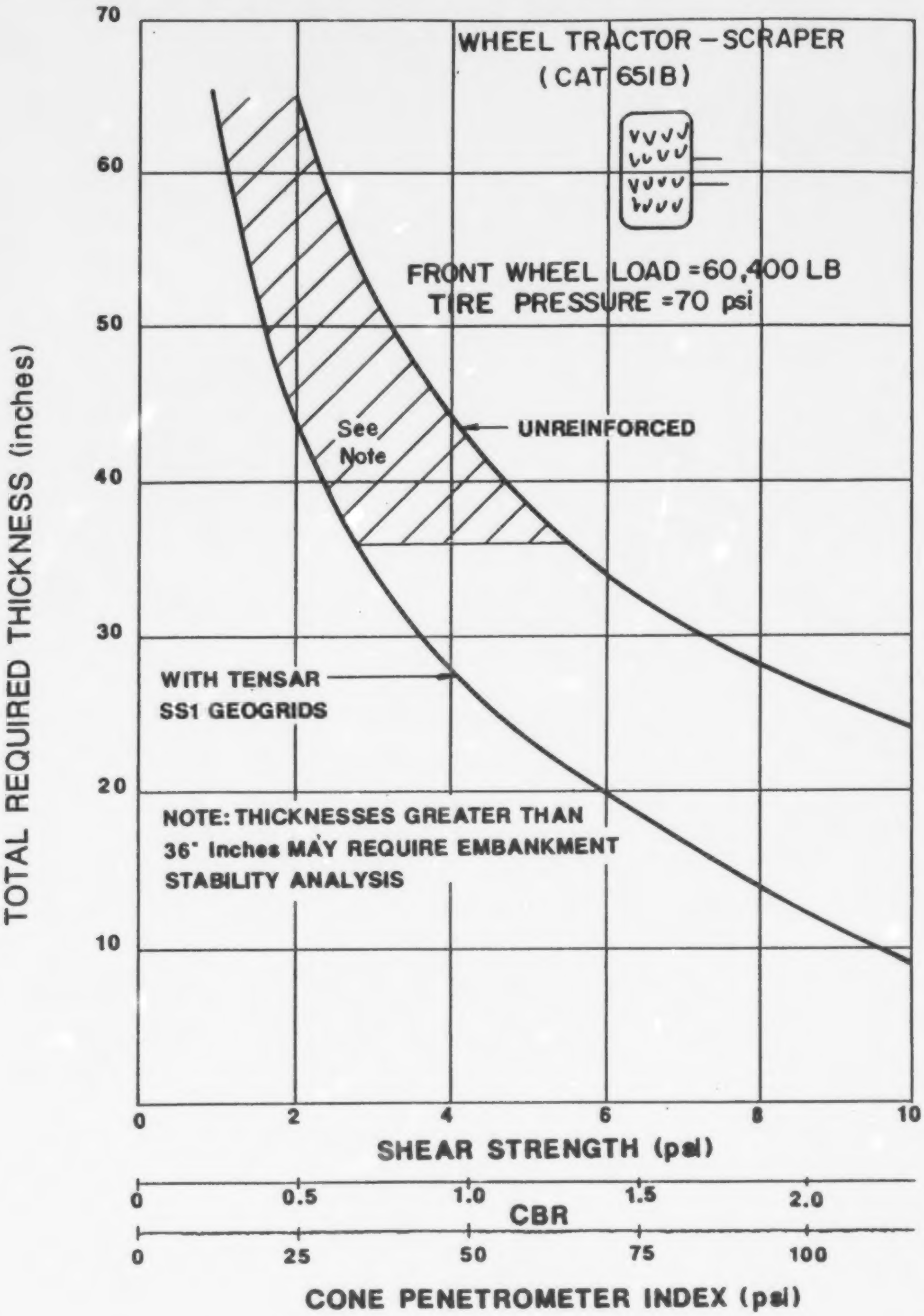


Figure 4-16 Thickness Requirements for 60,400 lb Single Wheel Loads

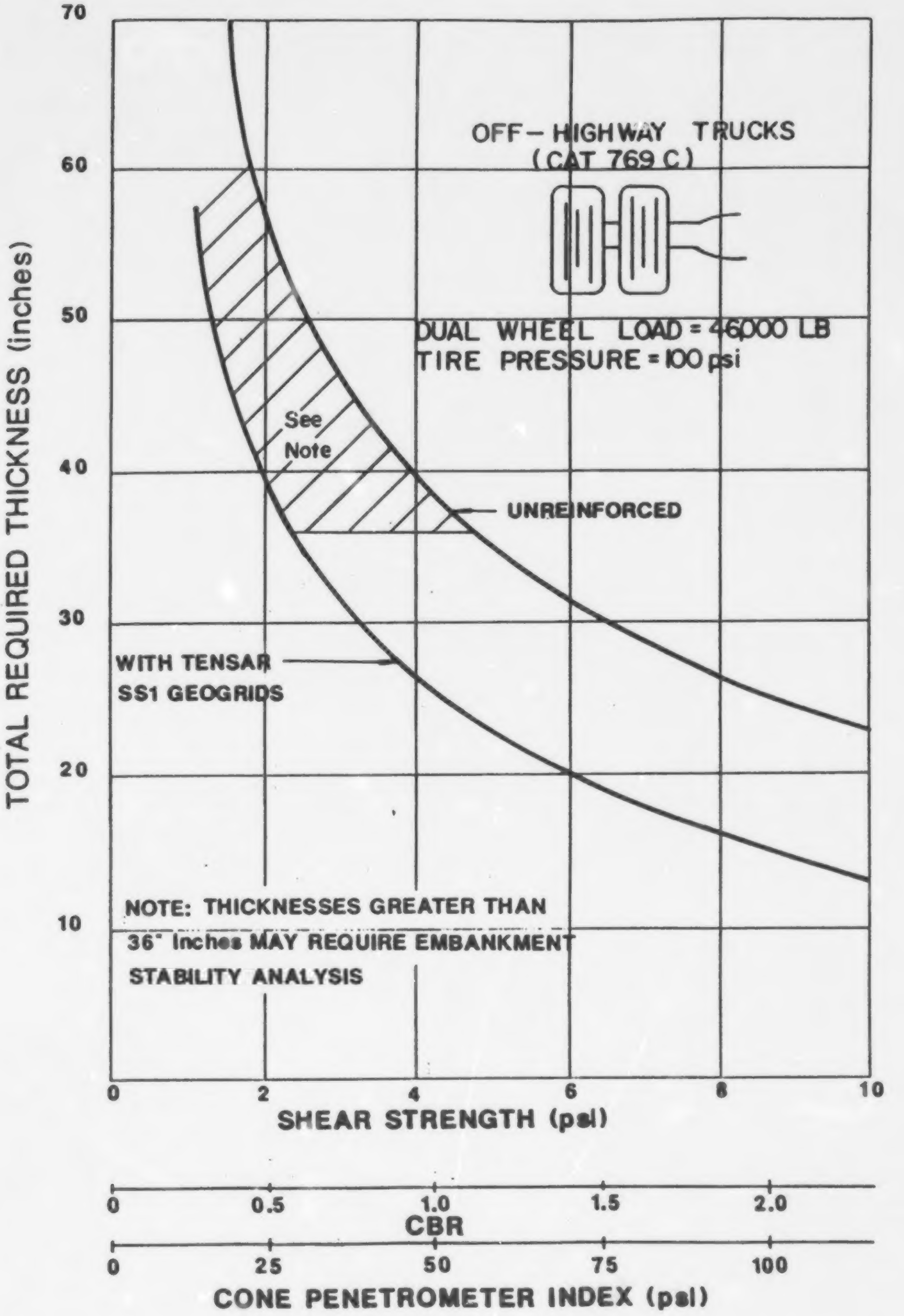


Figure 4-17 Thickness Requirements for 46,000 lb Dual Wheel Loads

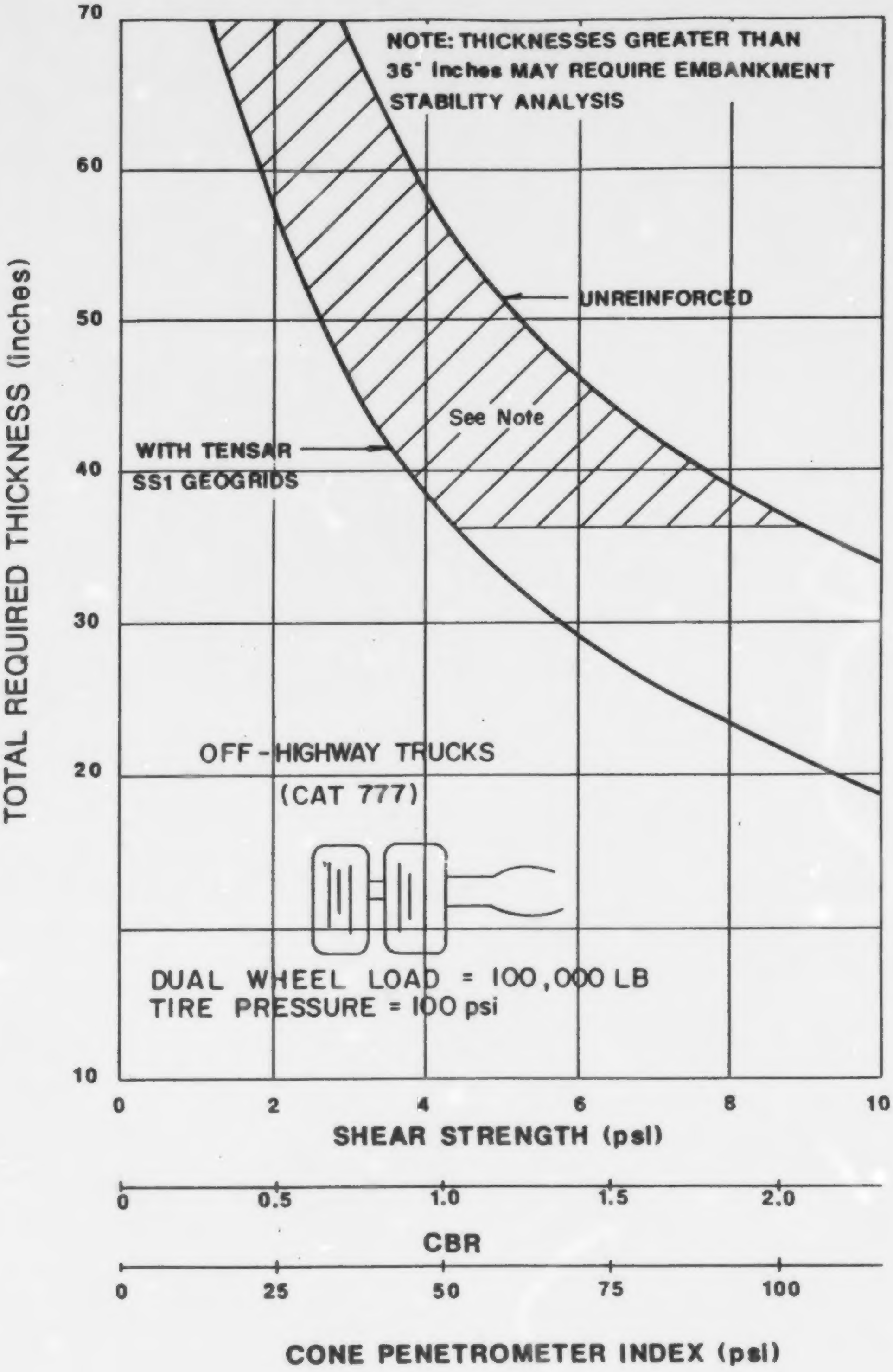


Figure 4-18 Thickness Requirements for 100,000 lb Dual Wheel Loads

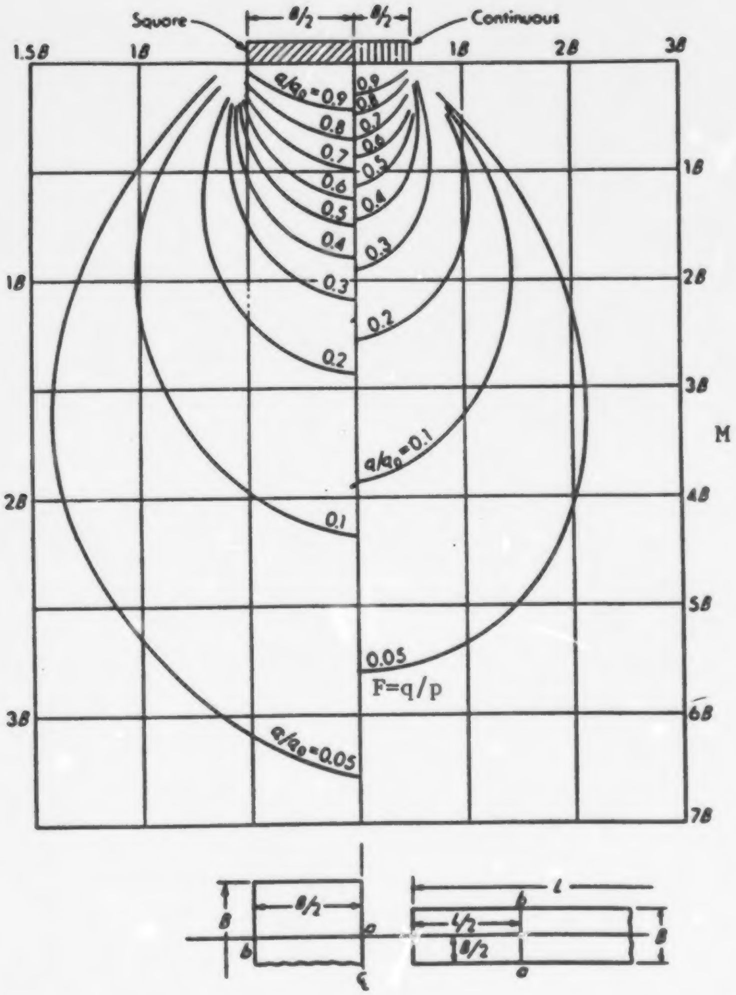


Figure 4-19 Pressure Isobars for Square and Long Footings

TABLE 4-16

Application Rate & Cost of Dust Control Palliatives

Chemical	Unit Cost* ($/litre)	Application Rate (l/m^2)	Cost per km per Application** (1986$)
Asphalt Emulsion	0.26	1.8	11,700
Calcium Chloride	0.11	2.2	6,000
Calcium lignosulfonate	0.30	1.5	11,300
Surfactant	2.95	0.009	650
Water	-	-	35

* supplied and applied
** for 25 m wide road surface

APPENDIX A

LIST OF SYMBOLS

LIST OF SYMBOLS

bcm - bank cubic metres
Mta - million metric tonnes per annum
hr - hours
t - metric tonnes
yr - year
m - metres
$M/km - million dollars per kilometre
ROM - run-of-mine material
CMP - corrugated metal pipe
$/op.hr - dollars per operating hour
Mbcm - million bank cubic metres
mph - miles per hour
HDPE - high density polyechelene

APPENDIX B

Fig. B-1 Meteorological Conditions - Boundary Dam Mine
Fig. B-2 Meteorological Conditions - Line Creek Mine
Fig. B-3 Meteorological Conditions - Pointearth Mine
Fig. B-4 Meteorological Conditions - Quintette Mine
Fig. B-5 Meteorological Conditions - Suncor & Syncrude Mines
Fig. B-6 Meteorological Conditions - Whitewood Mine

Table B-1 Years of Record at Each Meteorological Station

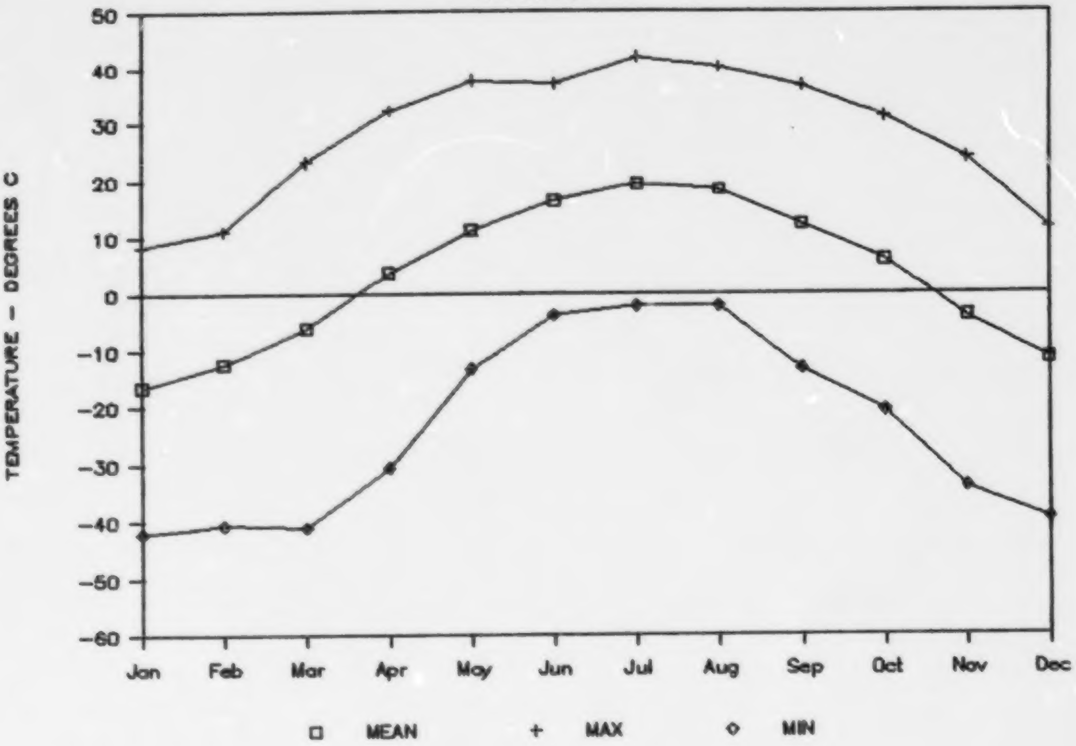
TABLE B-1

Years of Record at Each Meteorological Station

Mine	Meteorological Station		Years of Record
	Location	Approx. Dist. from Mine (km)	
Boundary Dam	Weyburn, Sask	50	25-29
Suncor	Fort McMurray Airport	60	30
Whitewood	Stoney Plain, Alta.	40	5-19
Line Creek	Minesite	-	2
Quintette	Minesite	-	8

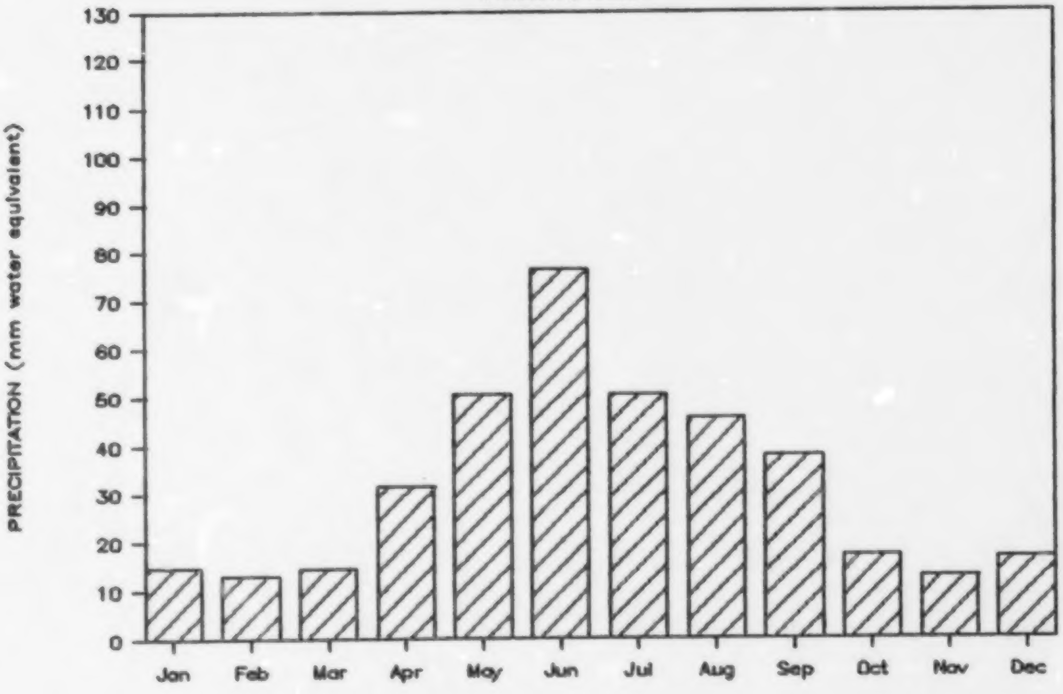
MONTHLY TEMPERATURE 1951 – 1980

WEYBURN, SASK.



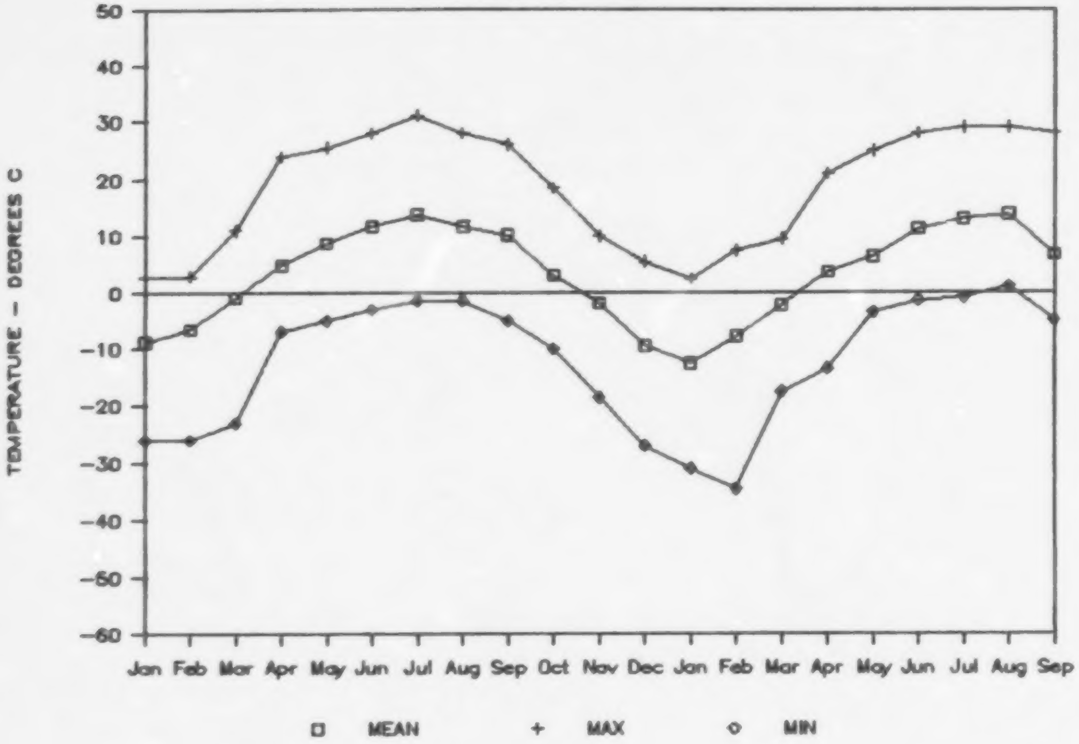
MONTHLY PRECIPITATION 1951 – 1980

WEYBURN, SASK.



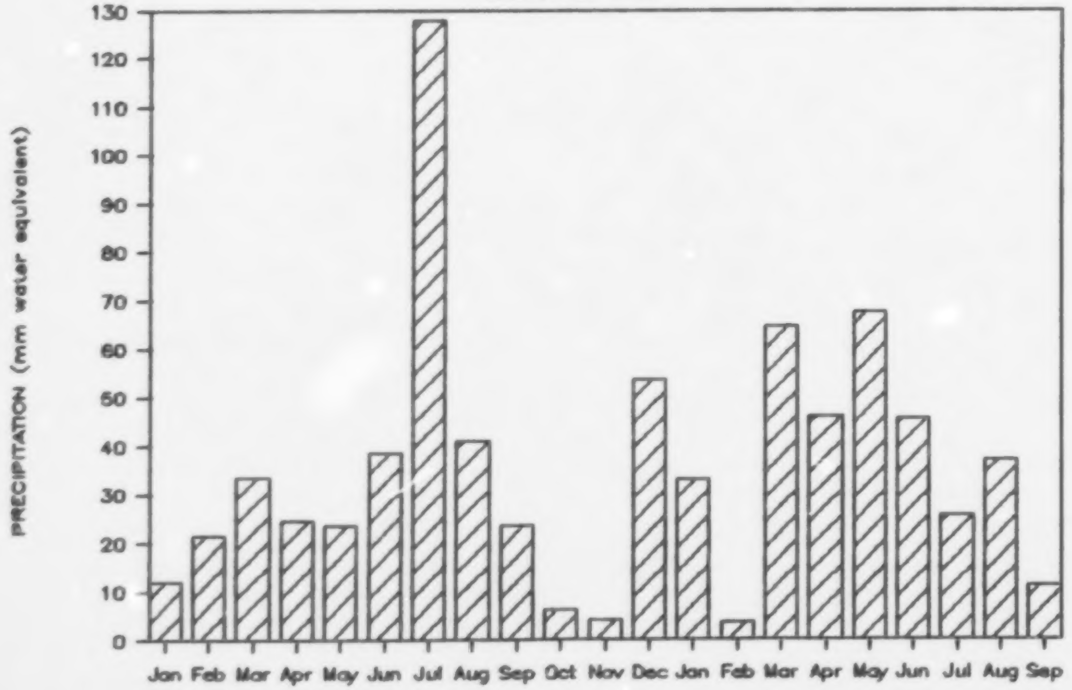
MONTHLY TEMPERATURE 1987 – 1988

LINE CREEK MINE



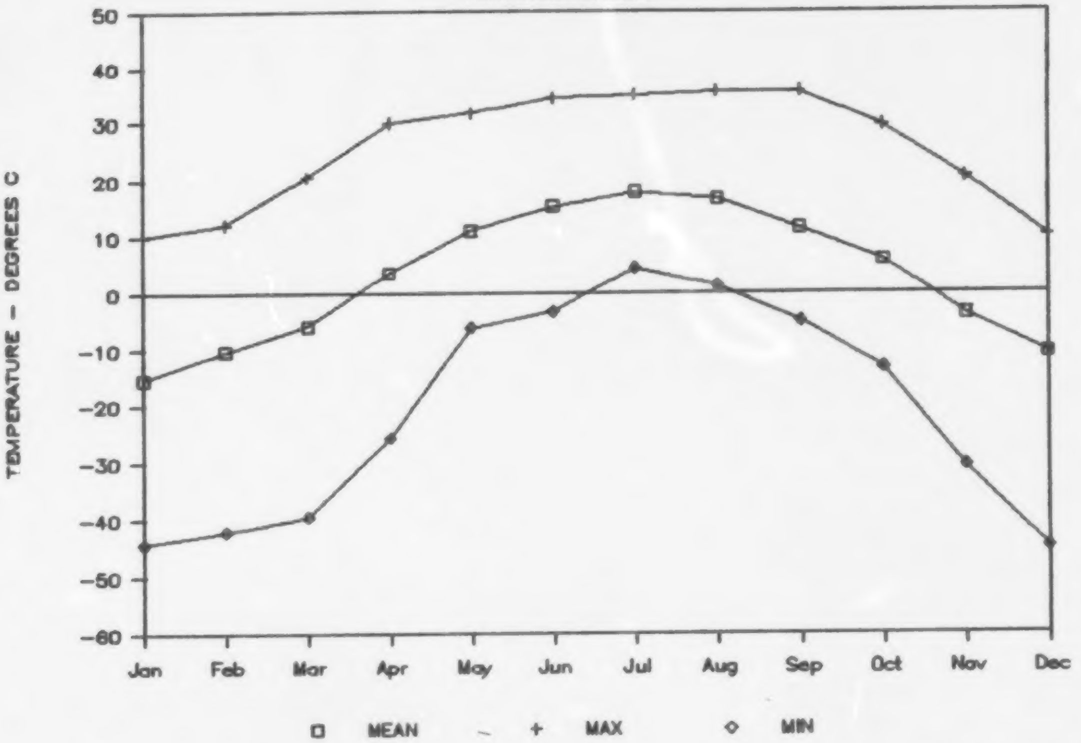
MONTHLY PRECIPITATION 1987 – 1988

LINE CREEK MINE



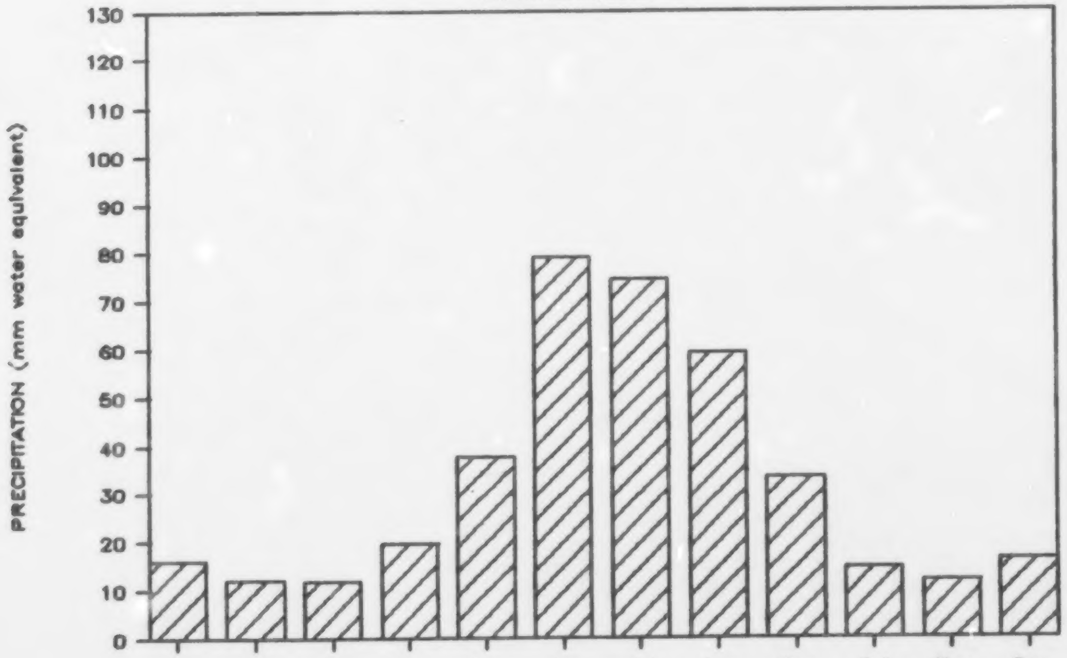
MONTHLY TEMPERATURE 1951 – 1980

FORESTBURG, ALTA



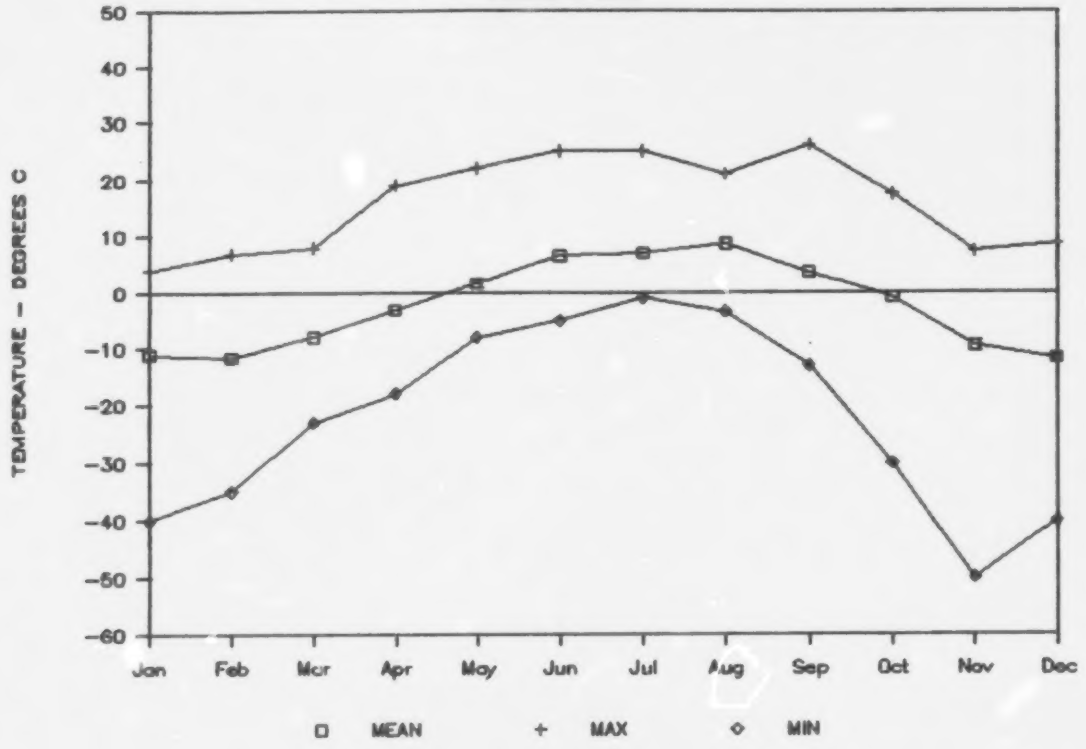
MONTHLY PRECIPITATION 5 – 19 YR RECORD

FORESTBURG, ALTA



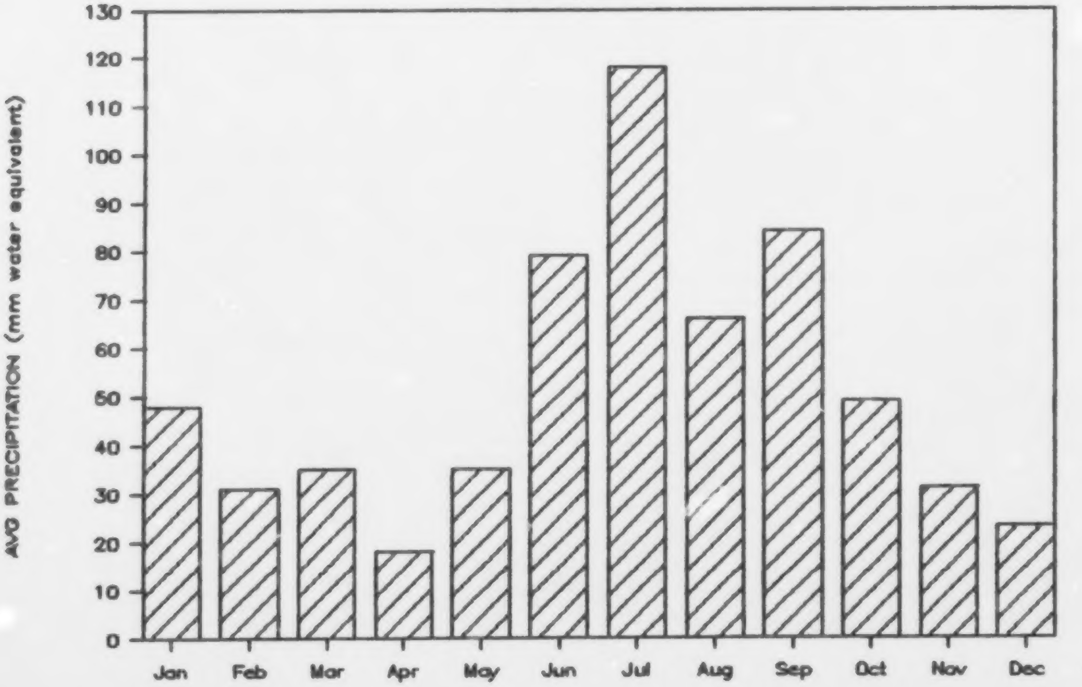
MONTHLY TEMPERATURE 1981 – 1988

QUINTETTE MINE



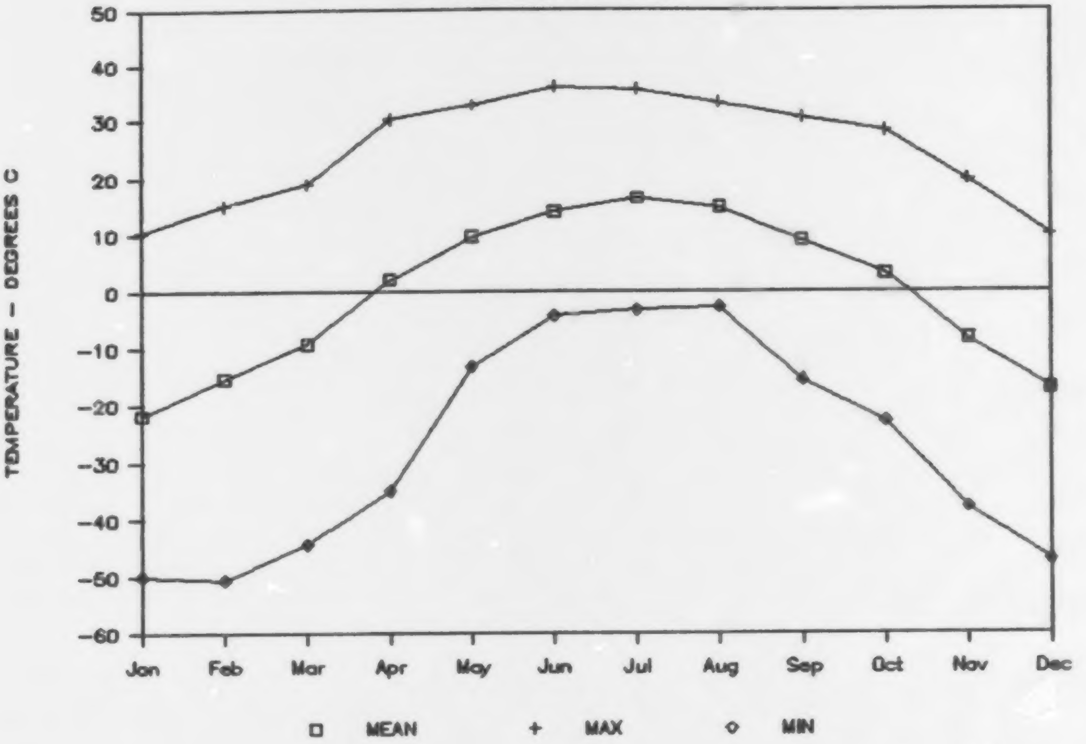
MONTHLY PRECIPITATION 1981 – 1988

QUINTETTE MINE



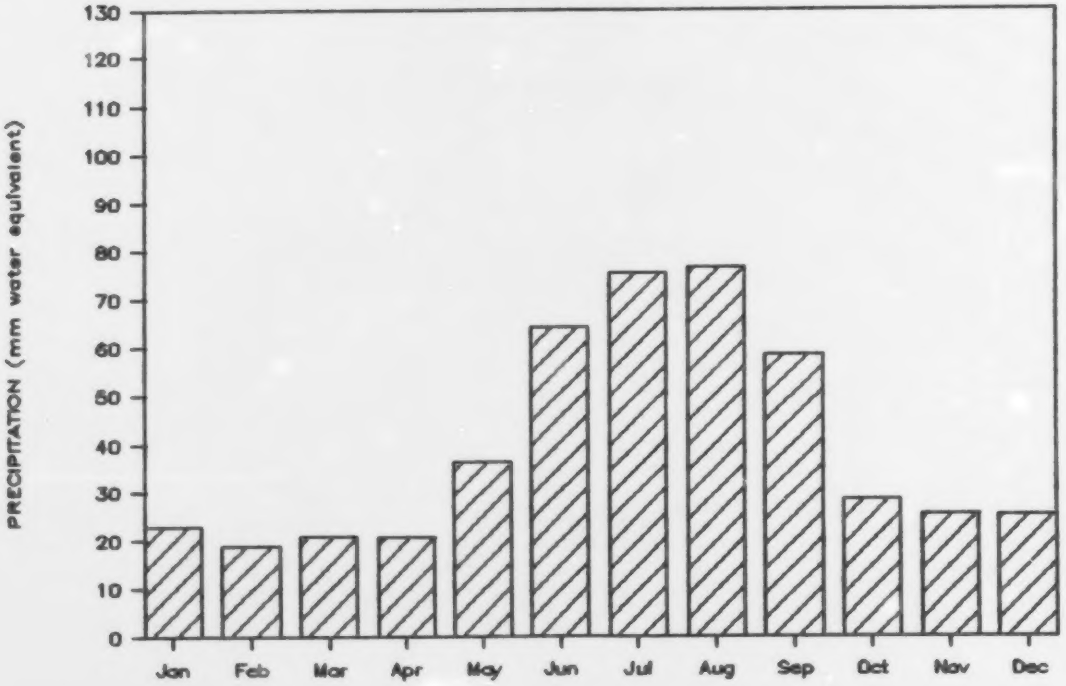
MONTHLY TEMPERATURE 1951 – 1980

FORT McMURRAY AIRPORT



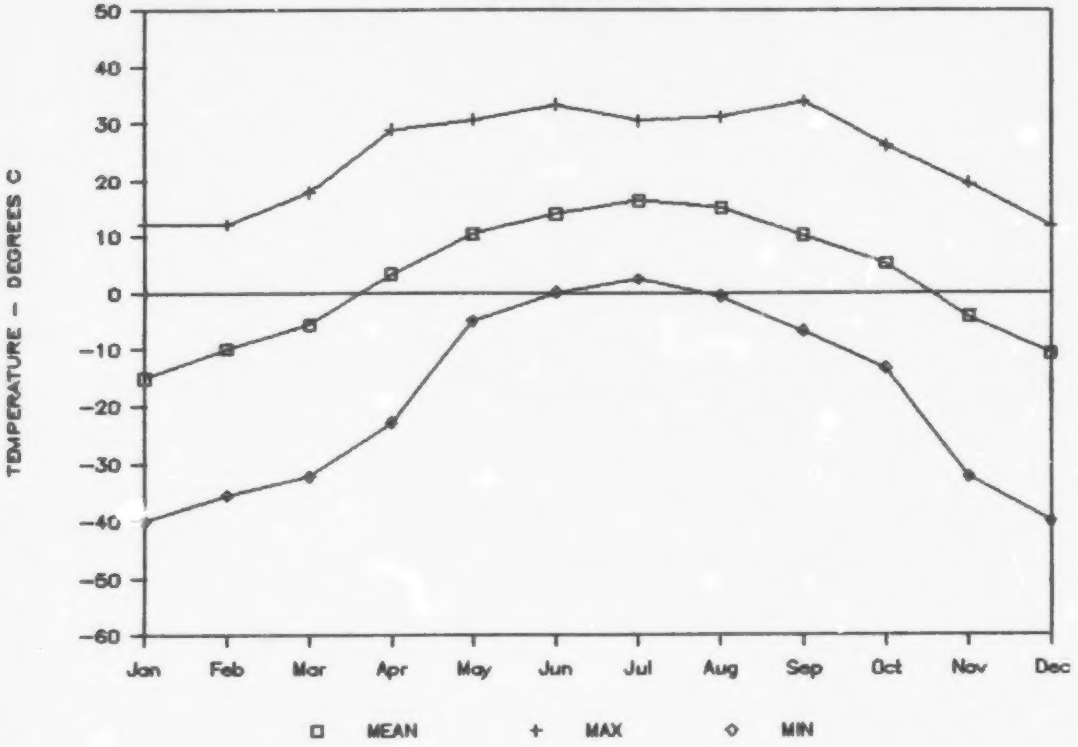
MONTHLY PRECIPITATION 1951 – 1980

FORT McMURRAY AIRPORT



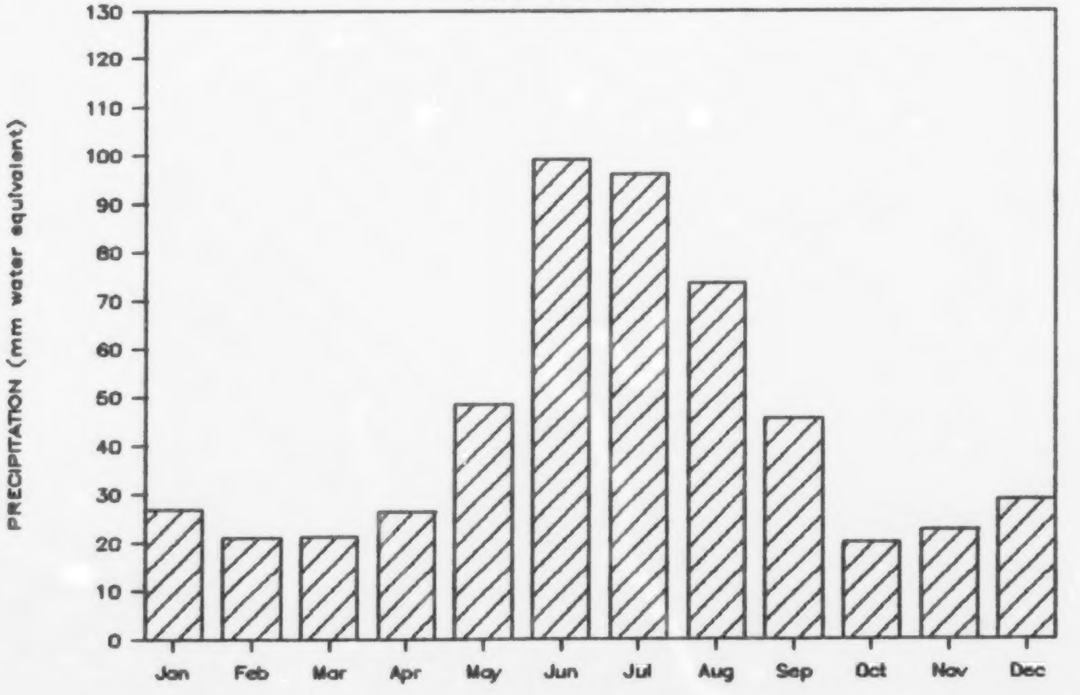
MONTHLY TEMPERATURE 1951 – 1980

STONEY PLAIN, ALTA.



MONTHLY PRECIPITATION 5 – 19 YR RECORD

STONEY PLAIN, ALTA.



APPENDIX C

EXXON GEOTEXTILE DESIGN MANUAL
FOR
UNMPAVED ROADS

UNPAVED ROADS

INTRODUCTION

This design manual has been prepared to assist you, the design engineer. If you are not already familiar with geotextiles, you may wish to first read Exxon's catalogue of general geotextile information.

The procedures presented here have been prepared in accordance with generally accepted engineering practices and methods. In particular, care has been taken to ensure that the methods presented are consistent with FHWA design procedures as established in their publication entitled GEOTEXTILE ENGINEERING MANUAL.

CAUTION: The methods presented here are applicable to conditions which are commonly encountered in unpaved road design. Nonetheless, the methods are not all-inclusive and the design engineer may encounter cases which are beyond their scope. In such an event, these methods should not be used; however, other, more sophisticated methods are available, and Exxon would be pleased to work with the design engineer to help him select an appropriate alternative approach.

APPLICATIONS

Exxon's GTF series of woven geotextiles are especially designed for use in unpaved road applications such as:

.. Pre-Paved Roads
.. Construction Roads
.. Detours
.. Haul Roads
.. Access Roads
.. Oil Exploration Roads
.. Agricultural Roads
.. Timber and Lumber Roads
.. Utility Access Roads
.. Manufacturing Storage Areas
.. Railroad Storage Areas
.. Access Roads

The definition of unpaved roads, as the phrase is used in this manual, is a road with an aggregate course, whose design is based on currently accepted unpaved road design concepts and methods and whose total anticipated travel is less than 10,000 vehicle passes. This definition is consistent with the definition of "Temporary Roads" in the FHWA GEOTEXTILE ENGINEERING MANUAL. The road may or may not have a thin flexible wearing course.

The use of Exxon woven GTF fabrics in unpaved road applications is most cost effective when subgrade soils are weak, i.e., CBR < 3. As subgrade strengths increase above this level, Exxon woven GTF fabrics become less beneficial, and, when subgrades are strong, Exxon woven GTF fabrics are not needed as a structural portion of the roadway. Drainage, erosion control, and other Exxon woven GTF fabrics applications which are ancillary to the roadway are of course still appropriate.

Most problem soils (i.e., those whose problem properties can be addressed through the use of Exxon woven GTF fabrics), fall into one or more of the following categories:

1) Saturated cohesive soils
2) Saturated fine non-cohesive or low cohesive soils
3) Organic soils
4) Soils with great variations in moisture content

It is important to recognize that, in some cases, geotextiles are not only effective in road construction, but are critical to the construction, i.e., it would be impractical to build the road without geotextiles. Simply stated, Exxon woven GTF fabrics now make it possible in some cases to build roads where no road would have been built in the past! Even when alternate methods such as lime stabilization or de-mucking are available, they are usually more expensive and time consuming.

EXXON GTF WOVEN GEOTEXTILES

UNPAVED ROAD FUNCTIONS

Exxon's GTF series of woven GTF fabrics can benefit unpaved road construction in several ways:

1) Separation
2) Construction advantages
3) Reinforcement

Separation

The most common cause of failure of unpaved roads is contamination and/or mixing of the aggregate course. Exxon's woven GTF fabrics can prevent the mixing of the aggregate course and the subgrade.

There are two aspects of this separation function:

1) The GTF woven geotextiles prevent expensive aggregate from "punching down" and being lost to the subgrade.
2) The GTF woven geotextiles prevent fines from "pumping up", and/or being displaced upward by intruding aggregate, and thereby prevent these fines from fouling and lubricating part or all of the aggregate.

Unpaved road design methods predict aggregate course thicknesses which are adequate if and only if the aggregate remains clean, intact, and separate.

Figure 1 shows an unpaved road as it is designed without geotextiles.

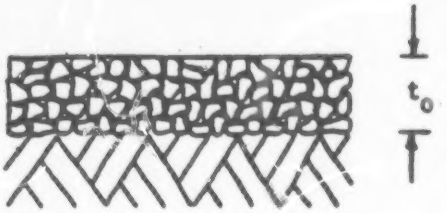
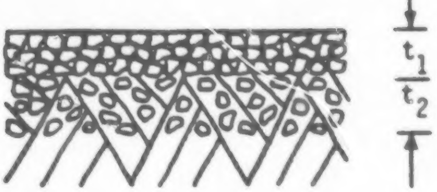
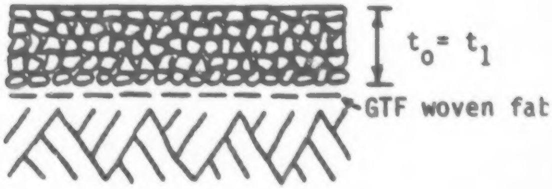


Figure 2 shows the same road after a few weeks/months of use.



Note: that t_1 in figure 2, the effective useful base course thickness, is much less than t_o, the required design thickness.

Figure 3 shows the aggregate intact, even after considerable use, because of the presence of the GTF woven geotextile. ($t_1 = t_o$)



The aggregate savings which result from the use of Exxon woven GTF fabrics for separation can be very significant. In some portions of the United States, for example, estimators routinely add 30% - 40% to the design compacted volume of aggregate in order to allow for the loss of aggregate to a poor subgrade (i.e., the contractor buys 30% - 40% more aggregate than is shown on the drawings). In the case of very soft subgrades, this aggregate loss can exceed 100% of the original design thickness.

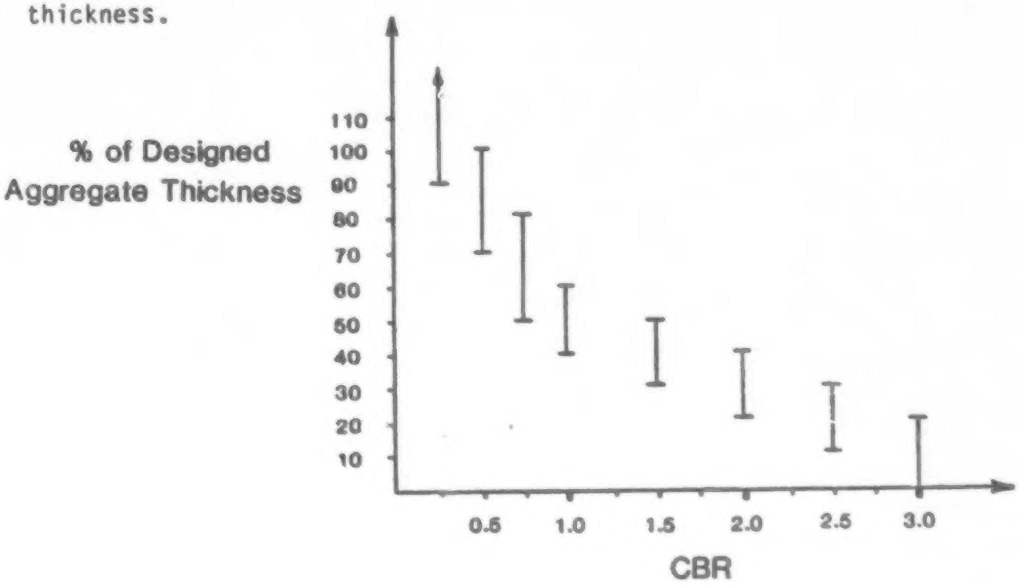


Figure 4. Aggregate loss to weak subgrades

Figure 4 is an example of typical aggregate loss expected. Although the actual extent of aggregate loss varies with type of aggregate, type of subgrade, moisture content, location, loads, etc., figure 4 is typical for many locations under normal construction loads. The aggregate loss which is shown on figure 4 must be compensated for by either the designer or the contractor. In any case, the use of Exxon woven GTF fabrics can result in saving the cost of all this additional aggregate.

Construction Advantages

Exxon's woven GTF fabrics offer a major advantage to contractors involved in the construction of unpaved roads on weak subgrades. One of the greatest problems associated with this type of project is the lack of initial access for construction equipment; i.e., the soils are too weak to support even the initial efforts at construction.

Ironically, it is often the case that the finished road section could be supported, but there is no good way of getting all of the road materials initially in place. As a result, the contractor must undertake extensive de-mucking, lime stabilization or similarly expensive operations. Exxon woven GTF fabrics can solve this expensive problem, because they provide the separation necessary to keep the aggregate material intact and the reinforcement to provide a sound working platform.

The subsequent savings are often as much as 20% to 50% of the cost of the road!

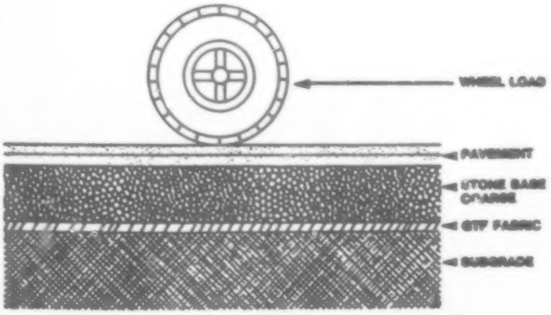


Photo 1

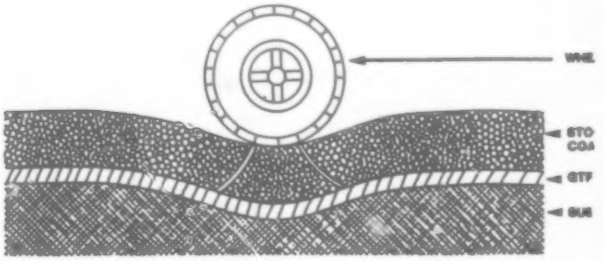


Photo 2

Reinforcement

Exxon's GTF woven geotextiles are designed to produce a strong reinforcing effect on unpaved roads. This allows the construction of unpaved roads on subgrades which are otherwise too weak to support the road without extensive de-mucking, surcharging, or some other preparation.

This reinforcement action of the GTF woven geotextiles works in three ways:

1) Membrane Effect
2) Aggregate Course and Subgrade Restraint
3) Lateral Restraint

Membrane effect is best described by first considering the typical woven geotextile stress-strain curve shown on figure 5. It can be seen that, for any given strain, there is a proportionate stress which is developed.

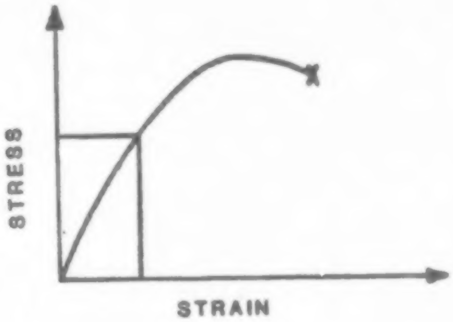


Figure 5

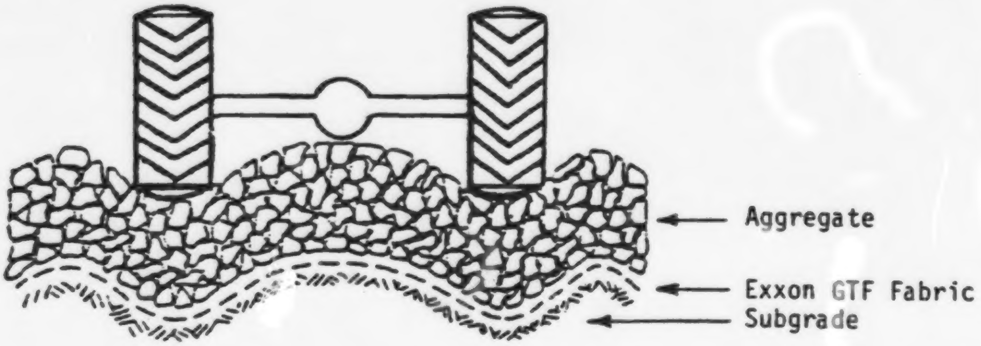


Figure 6.

In figure 6 the GTF woven geotextile is shown in a strained condition due to the initial rutting of the passing vehicles. Each portion of the GTF woven geotextile which is strained has of course developed a proportionate stress, and a component of that stress acts to support imposed loads; this is called the membrane effect.

It is important to note here that the GTF woven geotextile must first be strained in order to develop the membrane effect. Accordingly, the proper construction procedure is to allow approximately 3 inches of rutting to develop following initial construction (or to pre-rut) and then to fill in the ruts and finish the surface.

Aggregate course restraint is the ability of the GTF woven geotextile to lock the aggregate into place and thereby prevent shear failure in the aggregate itself.

Subgrade restraint is the ability of the GTF woven geotextile to prevent localized shear failure or "punching through" in the subgrade. Once the localized shear failure is prevented, the only possible subgrade failure mode is in "generalized shear"; and it has long been established (first by Terzaghi & Peck), that generalized shear can only occur at much higher imposed loads. As a result, the GTF woven geotextile increases the road carrying capacity by an amount equivalent to the difference between the load required for localized shear failure and that required for generalized shear failure.

Lateral restraint provided by a geotextile may also resist bearing failure in the base course. If the geotextile is placed in the road structure at a depth which interferes with the normal bearing failure surfaces, as shown in figure 7, failure must occur along an alternate surface. Thus, the ultimate bearing capacity is increased and an increase in the elastic modulus of the base is provided. An increase in stiffness of the base also reduces the magnitude of stresses transmitted to the subgrade.

THE ULTIMATE RESULT OF THE GTF WOVEN GEOTEXTILE REINFORCEMENT IS THAT UNPAVED ROADS CAN NOW BE CONSTRUCTED ON VERY WEAK SUBGRADES, AND, IN SOME CASES, IN PLACES WHERE NO ROAD WOULD HAVE BEEN PRACTICAL IN THE PAST.

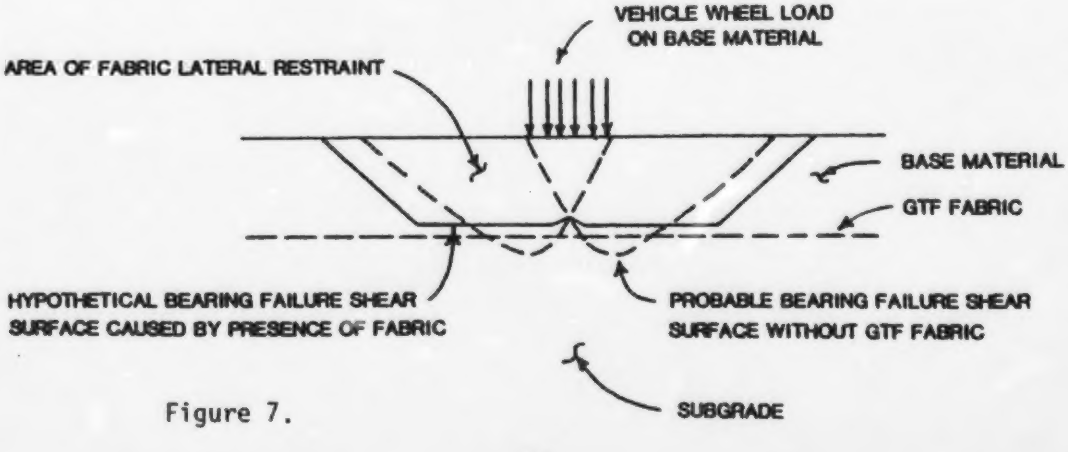

VEHICLE WHEEL LOAD ON BASE MATERIAL
AREA OF FABRIC LATERAL RESTRAINT
BASE MATERIAL
GTF FABRIC
HYPOTHETICAL BEARING FAILURE SHEAR SURFACE CAUSED BY PRESENCE OF FABRIC
PROBABLE BEARING FAILURE SHEAR SURFACE WITHOUT GTF FABRIC
SUBGRADE

Figure 7.

DESIGN PROCEDURES

The design procedures which are presented herein have been adapted from the FHWA "GEOTEXTILE ENGINEERING MANUAL". The use of these procedures allows the designer to properly select the required depth of aggregate for most of the commonly encountered combination of wheel loads, tire pressures, subgrade cohesions, and axle configurations. Both reinforced and unreinforced unpaved roads are considered; therefore, a relative cost-benefit analysis may be readily performed by the designer. This manual also contains a computer program with which the designer may determine aggregate depths for many of the combinations of loads, subgrades, reinforcement, etc.

While other design methods are also available, the methods presented herein have been selected because they may be adapted to the widest variety of conditions.

Note: The following prerequisites apply to all the design methods which are presented:

1) The aggregate layer must be;
    a) compacted to CBR 80
    b) cohesionless
    c) non-plastic

2) Passing vehicles must utilize the same ruts.

3) Vehicle passes are limited to 10,000.

4) Geotextile survivability criteria must be considered prior to final selection.

Tensile Modulus Considerations

GTF woven geotextiles are especially well suited to the reinforcement function because of their high tensile moduli, particularly in comparison to many nonwoven geotextiles.

In figure 8 it can be seen that at a given elongation T_w, the typical woven geotextile tensile stress is much greater than T_n the nonwoven geotextile tensile stress.

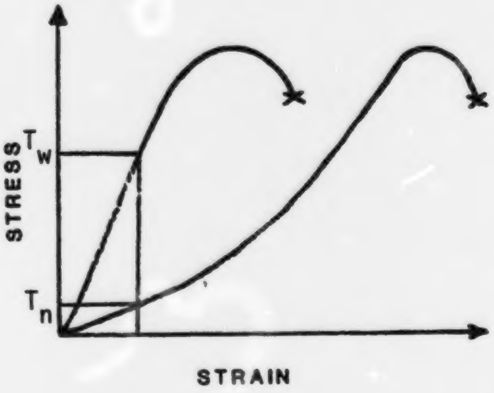


Figure 8

Because GTF woven geotextiles develop much of their tensile properties at relatively low elongations, comparably low deformations in the road are required for the GTF woven geotextiles to mobilize their membrane reinforcement properties.

In fact, a careful review of the state of the art literature shows that most researchers agree with the statement that "the higher the geotextile tensile modulus, the thinner the required thickness of aggregate layer".

As a practical matter, the design procedures which follow consider geotextile modulus only when subgrades are very weak, i.e., CBR <1. In these cases, however, where the design is difficult if not impossible without geotextiles, Exxon's GTF high modulus woven geotextiles can greatly simplify the design, as well as possibly result in great construction savings. Figure 9 relates subgrade CBR to the suggested method of design. The two methods of design are then presented in detail.

Recommended Design Method	CBR	Primary Geotextile Design Considerations
Giroud	< 1	Tensile Modulus, Survivability
Steward or Giroud	1 - 3	Survivability
Optional	> 3	Geotextile usually not required

Figure 9. Design Considerations as a function of CBR

Steward, Williamson and Mohney

The Steward et al. design method is based on both theor~~i~~etical analysis and empirical test results. Steward et al. determined that very little rutting (less than 2") would occur under even a relatively large number of load applications if stress levels in the subgrades were held to 2.8 or less times the undrained shear strength of the unreinforced subgrade, or 5.0 or less times the undrained shear strength of a fabric-reinforced subgrade. Furthermore, 3.3 times the undrained shear strength of the subgrade without fabric reinforcement or 6.0 with fabric reinforcement are the stress levels at which a great amount of rutting (greater than 6") will occur under a small number of axle loadings.

The following is the detailed design procedure for the Steward method:

a) Determine the maximum single wheel load, maximum dual wheel load and the maximum dual tandem wheel load anticipated for the unpaved road.

b) Determine the required aggregate thickness from the load-stress depth curves (figures 10, 11 and 12) for each maximum loading. Enter the curve with stresses equal to 2.8, 3.3, 5.0 and 6.0 times the subgrade undrained shear strength (i.e., $cNc_1 = c \times 2.8$; $cNc_2 = c \times 3.3$ $cNc_3 = c \times 5.0$ and $cNc_4 = c \times 6.0$ where c is the undrained shear strength of the subgrade in Psi).

c) The appropriate unreinforced aggregate thickness corresponds to the cNc_1 (i.e. $c \times 2.8$) reading if very little rut is desired, and cNc_2 (i.e., $c \times 3.3$) reading if a greater amount of rutting (i.e. larger than 4") is acceptable.

d) The appropriate geotextile reinforced aggregate thickness corresponds to the cNc_3 (i.e., $c \times 5.0$) reading if very little rut in desired, and cNc_4 (i.e., $c \times 6.0$) reading if a greater amount of rutting (i.e., larger than 4") is acceptable.

e) If more rutting occurs during construction than was designed for, the thickness should be increased at least as much as the thickness difference between 2.8 c and 3.3 c., or 5.0 c and 6.0 c, as appropriate.

f) Verify Survivability Criteria from Tables A, B and C prior to final selection.

Design example, Steward et al. Method

Given

Maximum single wheel load : 20.0 kips

Maximum dual wheel load : 20.0 kips

Maximum dual tandem wheel load : 24.0 kips

Subgrade CBR value = 1.00 (4.35 psi) relatively smooth surface

Aggregate course: subangular 1 1/2" gravel

Solution

a) Using N_c = 2.8
cNc = 4.35 x 2.8 = 12.18

1) from single wheel load chart, figure 10 (@ 20.0 kips)
depth = 27 in.

2) from dual wheel load chart, figure 11 (@ 20.0 kips)
depth = 25 in.

3) from dual tandem wheel load chart, figure 12 (@ 24.0 kips)
depth = 21 in.

b) using N_c = 3.3
cNc = 4.35 x 3.3 = 14.36

1) from single wheel load chart, figure 10 (@ 20.0 kips)
depth = 24 in.

2) from dual wheel load chart, figure 11 (@ 20.0 kips)
depth = 19 in.

3) from dual tandem wheel load chart, figure 12 (@ 24.0 kips)
depth = 17 in.

c) using N_c = 5.0
cN_c = 4.35 x 5.0 = 21.75

1) from single wheel load chart, figure 10 (@ 20.0 kips)
depth = 18 in.

2) from dual wheel load chart, figure 11 (@ 20.0 kips)
depth = 15 in.

3) from dual tandem wheel load chart, figure 12 (@ 24.0 kips)
depth = 14 in.

d) using N_c = 6.0
cN_c = 4.35 x 6.0 = 26.10

1) from single wheel load chart, figure 10 (@ 20.0 kips)
depth = 16 in.

2) from dual wheel load chart, figure 11 (@ 20.0 kips)
depth = 14 in.

3) from dual tandem wheel load chart, figure 12 (@ 24.0 kips)
depth = 12 in.

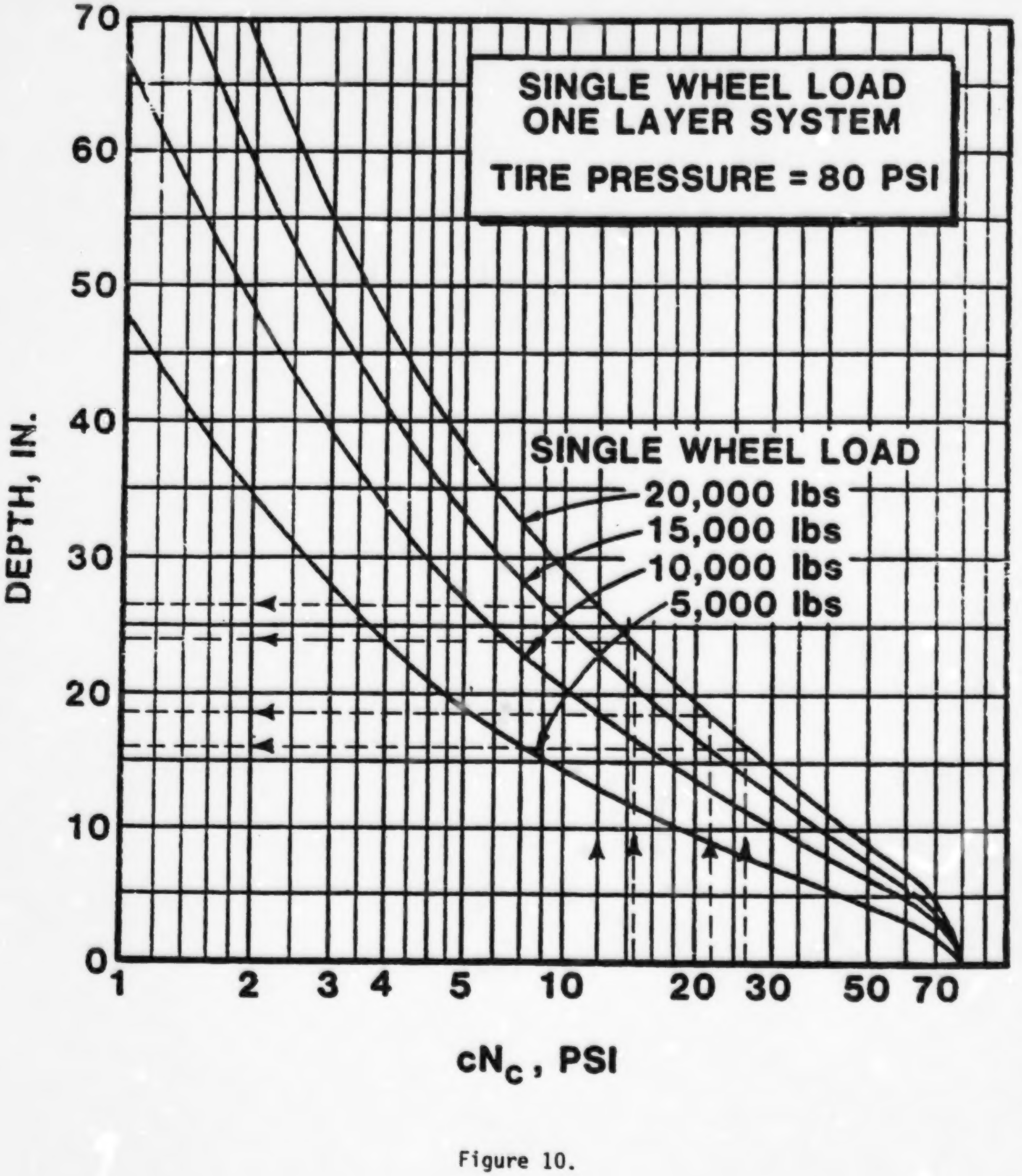


Figure 10.

From FHWA GEOTEXTILE ENGINEERING MANUAL, Christopher & Holtz, 1984

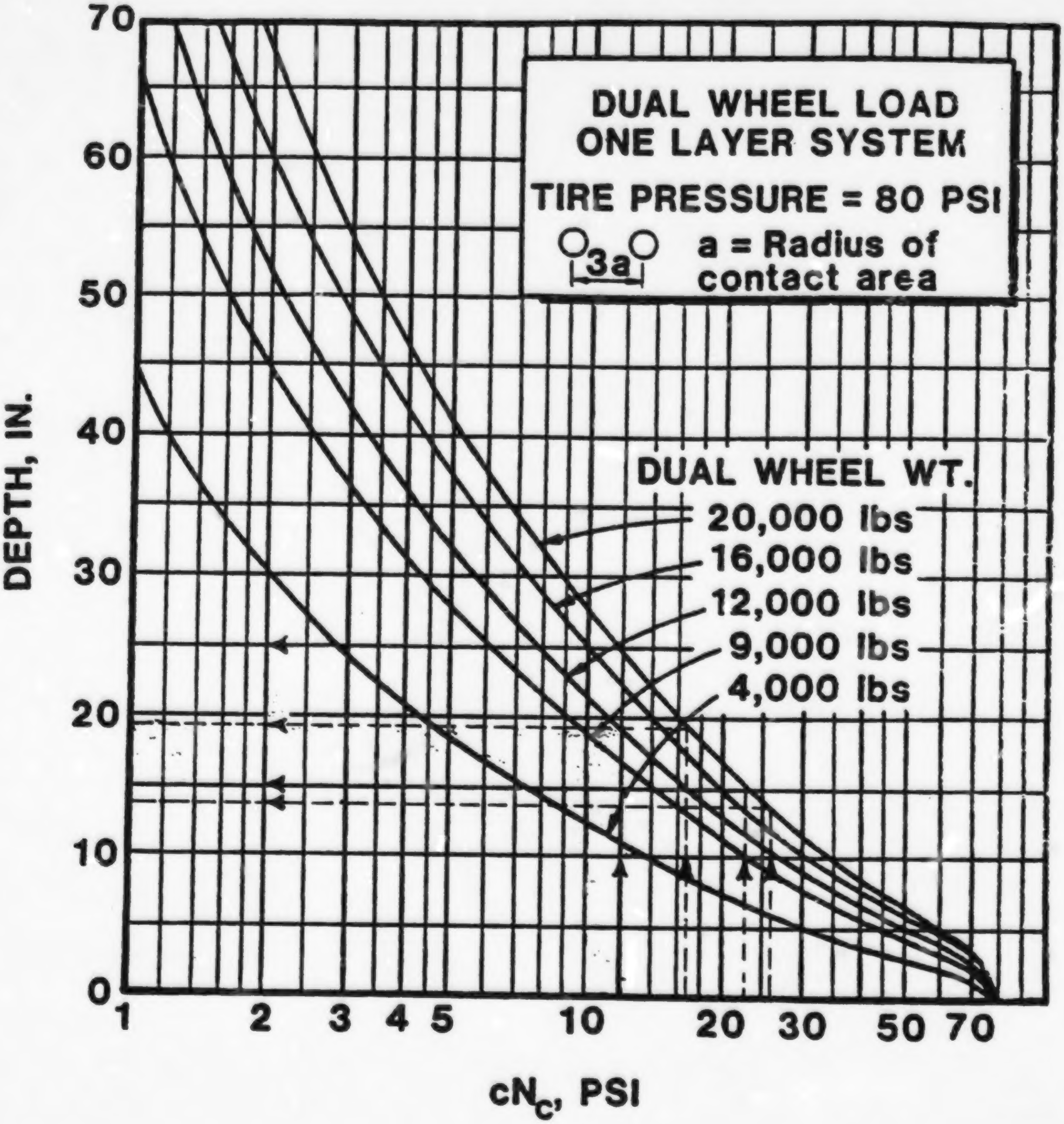


Figure 11.

From FHWA GEOTEXTILE ENGINEERING MANUAL, Christopher & Holtz, 1984

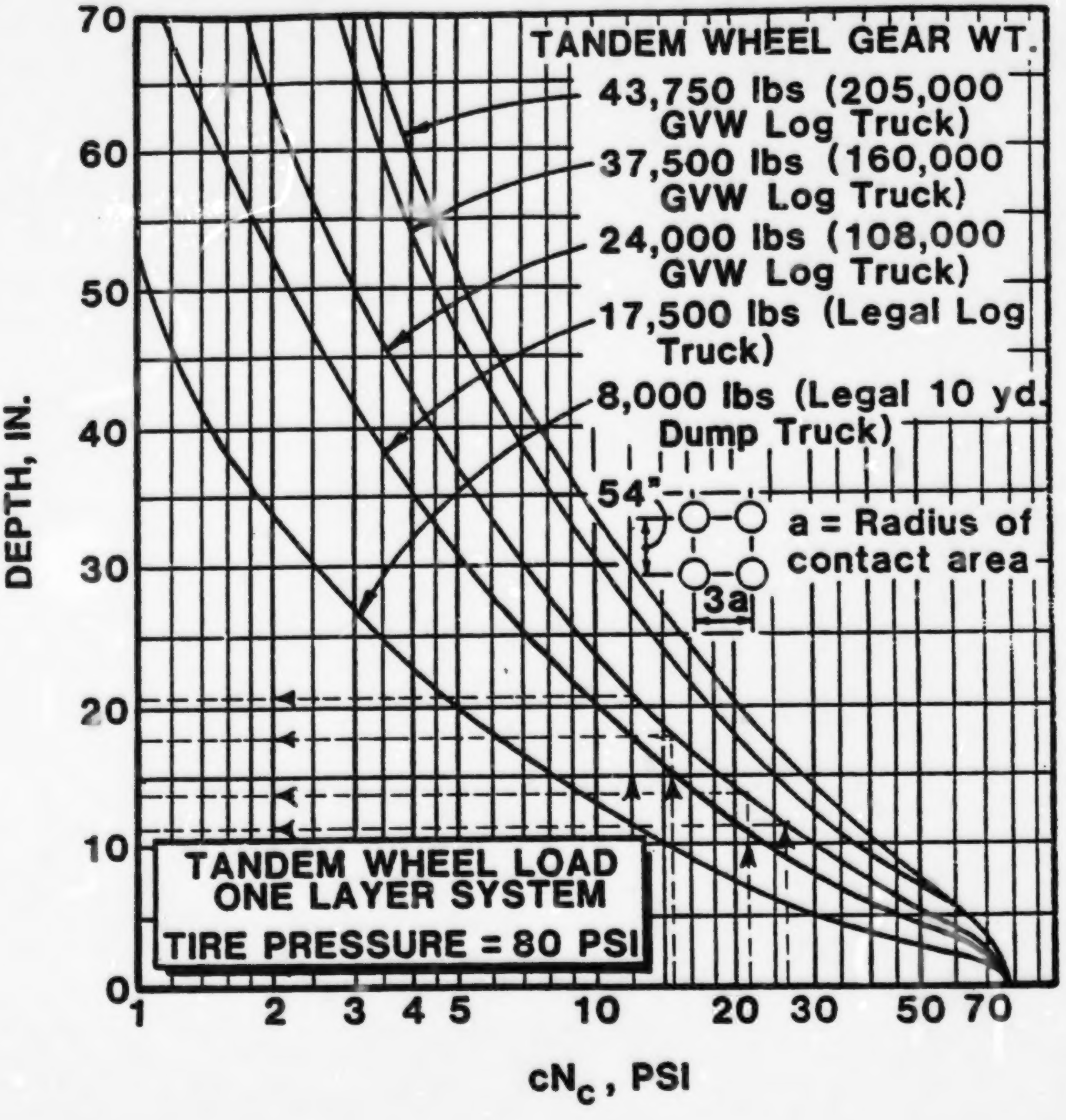


Figure 12.

From FHWA GEOTEXTILE ENGINEERING MANUAL, Christopher & Holtz, 1984.

TABLE A
*REQUIRED DEGREE OF FABRIC SURVIVABILITY AS A FUNCTION OF SUBGRADE CONDITIONS AND CONSTRUCTION EQUIPMENT

Subgrade Conditions	Construction Equipment and 6 In. 12 In. Cover Material Initial Lift Thickness		
	Low Ground Pressure Equipment (≤ 4 psi)	Medium Ground Pressure Equipment (> 4 psi, ≤ 8 psi)	High Ground Pressure Equipment (> 8 psi)
Subgrade has been cleared of all obstacles except grass, weeds, leaves, and fine wood debris. Surface is smooth and level such than any shallow depressions and humps do not exceed 6 In. in depth and height. All larger depressions are filled. Alternatively, a smooth working table may be placed.	Low	Moderate	High
Subgrade has been cleared of obstacles larger than small-to-moderate-sized tree limbs and rocks. Tree trunks and stumps should be removed or covered with a partial working table. Depressions and humps should not exceed 18 in. in depth and height. Larger depressions should be filled.	Moderate	High	Very High
Minimal site preparation is required. Trees may be felled, , and left in place. Stumps should be cut to project not more than 6 in. ± above subgrade. Fabric may be draped directly over the tree trunks, stumps, large depressions and humps, holes, stream channels, and large boulders. Items should be removed only if placing the fabric and cover material over tree will distort the finished road surface.	High	Very High	Not Recommended

NOTE:

1. Recommendations are for 6 in.-12 in. initial lift thickness. For other initial lift thicknesses:
   - 12 In.-18 In.: Reduce survivability requirement 1 level
   - 18 In.-24 In.: Reduce survivability requirement 2 levels
   - > 24 In.: Reduce survivability requirement 3 levels

   Survivability levels are, in increasing order: low, moderate, high, and very high.
2. For special construction techniques such as pre-rutting, increase fabric survivability requirement 1 level.
3. Placement of excessive initial cover material thickness may cause bearing failure of soft subgrades.

*From FHWA GEOTEXTILE ENGINEERING MANUAL, Christopher & Holtz, 1984

TABLE B

*REQUIRED DEGREE OF FABRIC SURVIVABILITY AS A FUNCTION OF COVER MATERIAL AND CONSTRUCTION EQUIPMENT

	6 In.-12 In. Initial Lift Thickness		12 In.-18 In. Initial Lift Thickness		18 In.-24 In. Initial Lift Thickness	> 24 In. Initial Lift Thickness
	Low Ground Pressure Equipment (≤ 4 psi)	Medium Ground Pressure Equipment (> 4 psi, ≤ 8 psi)	Medium Ground Pressure Equipment (> 4 psi, ≤ 8 psi)	High Ground Pressure Equipment (> 8 psi)	High Ground Pressure Equipment (> 8 psi)	High Ground Pressure Equipment (> 8 psi)
Fine sand to ±2-in.-dia gravel, rounded to subangular	Low	Moderate	Low	Moderate	Low	Low
Coarse aggregate with diameter up to one-half proposed lift thickness, may be angular	Moderate	High	Moderate	High	Moderate	Low
Some to most aggregate with diameter greater than one-half proposed lift thickness, angular and sharp-edged, few fines	High	Very High	High	Very High	High	Moderate

NOTE:

1. For special construction techniques such as pre-rutting, increase fabric survivability requirement 1 level.
2. Placement of excessive initial cover material thickness may cause bearing failure of soft subgrades.

*From FHWA GEOTEXTILE ENGINEERING MANUAL. Christopher & Holtz, 1984

TABLE C

AASHTO-AGC-ARTBA JOINT COMMITTEE

(Interim Specifications)

MINIMUM[1] FABRIC PROPERTIES REQUIRED FOR FABRIC SURVIVABILITY

Required Degree of Fabric Survivability		Grab Strength (minimum values) (lbs.)	Puncture Strength[2] (lbs.)	Burst Strength[3] (psi)	Trapezoidal[4] Tear (lbs.)
Very High	Min. Req. Values	270	110	430	75
	GTF 300 Values	300	135	600	115
High	Min. Req. Values	180	75	290	50
	GTF 200 Values	200	100	450	90
Moderate	Min. Req. Values	130	40	210	40
	GTF 150 Values	130	65	310	55
Low	Min. Req. Values	90	30	145	30
	GTF 110 Values	110	60	300	55

[1] All values represent minimum average roll values (i.e., any roll in a lot should meet or exceed the minimum values in this table).

[2] ASTM D-751-68, Tension Testing Machine with ring clamp, steel ball replaced with a 5/16 inch diameter solid steel cylinder with flat tip centered within the ring clamp.

[3] ASTM D-751-68, Diaphragm Test Method.

[4] ASTM D-1117, either principal direction.

Based on FHWA GEOTEXTILE ENGINEERING MANUAL, Christopher & Holtz, 1984

Answer

- 27 in. without geotextile is recommended for little rutting (2") and more than 1000 passages
- 24 in. without geotextile is recommended for deep rutting (4") and less than 100 passages
- 18 in. reinforced with geotextile is recommended for little rutting (2") and more than 1000 passages
- 16 in. reinforced with geotextile is recommended for deep rutting (4") and less than 100 passages
- Verification of survivability criteria prior to final selection;

  Table A suggests a moderate degree of fabric survivability for medium ground pressure equipment and the relatively smooth surface.

  Additionally, Table B also suggests a moderate degree of fabric survivability since the available aggregate is comprised of fine sand.

  Lastly, Table C indicates that the appropriate Exxon woven geotextile is GTF150 for moderate survivability applications. The associated mechanical properties are also listed in Table C.

The Giroud Noiray Algorithm

The Giroud-Noiray design method for the determination of aggregate thickness for reinforced unpaved road is the only method recommended for soils with CBR values less than 1 because it accepts the widest variety of design parameters and utilizes the geotextile tensile modulus to combat the very weak soils.

The variables considered are :

- Number of vehicle passages (less than 10,000)
- Equivalent axle loads
- Axle configurations
- Tire pressures
- CBR values
- Geotextile tensile strengths
- Geotextile secant moduli
- Rut depths

The Giroud-Noiray algorithm involves three steps;

1) Computation of the following equation to determine the aggregate thickness of the unreinforced unpaved road with traffic;

$$*h_o' = \frac{125.70 \log N + 496.52 \log P - 294.14\ r - 2412.42}{cu^{0.63}}$$

2) Computation of the following equation to determine the aggregate thickness of the unreinforced unpaved road without traffic;

$$cu = \frac{P}{2\ (A + 1.2\ h_o)\ (B + 1.2\ h_o)}$$

---

* Webster et al. algorithm as modified by Giroud.

Ref.: "Geotextile-Reinforced Unpaved Road Design". Journal of the Geotechnical Division, ASCE, vol. 107, No GT9, pp. 1233-1254, Sept. 1981.

where; cu = cohesion of subgrade soil in Pascals
h_0 = thickness of aggregate layer without traffic without geotextile in meters

A & B = coefficients related to axle configuration and loading conditions

3) Computation of the following Giroud-Noiray equation to determine the aggregate thickness of the reinforced unpaved road without traffic;

$$^{*}\quad (\pi + 2)\, cu = \frac{P}{2(B + 1.2h)(L + 1.2h)} - \frac{K\varepsilon}{a(1 + (a/2s)^2)^{\frac{1}{2}}}$$

where cu = cohesion of subgrade soil in Pascals
P = axle load in Newton
h = thickness of aggregate layer without traffic with geotextile in meters
K = Geotextile secant modulus at elongation ($N\ m^{-1}$)
= Geotextile elongation (as a percentage, dimentionless)
B, L, a & s = coefficients related to axle confifurations and loading conditions

* Giroud-Noiray Algorithm

Ref.: "Geotextile-Reinforced Unpaved Road Design". Journal of the Geotechnical Division, ASCE, vol. 107, No GT9, pp. 1233-1254, Sept. 1981.

4) Computation of the aggregate thickness of the reinforced unpaved road with traffic by combining the 3 previous equations;

$$h' = h + h_o' - h_o$$

where h' : aggregate thickness of reinforced unpaved road with traffic
h : aggregate thickness of reinforced unpaved road without traffic
h_o': aggregate thickness of unreinforced unpaved road with traffic
h_o : aggregate thickness of unreinforced unpaved road without traffic

Solving these equations requires either extensive engineering time and effort or the computer program presented in the following section.

5) Prior to final selection, survivability criteria need to be considered.

COST CONSIDERATIONS

Those design engineers who are unfamiliar with the use of GTF woven geotextiles may wish to complete a Cost Benefit Analysis (CBA) in order to assure themselves and their clients that the savings do indeed justify the use of GTF woven geotextiles.

To this end, we have prepared the following list of CBA considerations. It should be a straightforward matter for the design engineer to add these considerations to his "no-geotextile" CBA and thereby develop the comparable "yes-geotextile" CBA.

Be certain to allow for:

1) Aggregate savings - be certain that the no-geotextile alternate design method includes an allowance for aggregate lost to the subgrade, i.e., the no-geotextile alternate should include an aggregate thickness which is sufficient to carry the load after an allowance is made for loss of aggregate to the subgrade. (see figure 4.)

2) Savings in required construction equipment, e.g., no required de-mucking equipment.

3) Savings in required construction labor, e.g., no required operators for de-mucking equipment.

4) Faster construction time with the resultant savings in equipment, labor and cost of construction funding.

5) In some cases, the road is simply uneconomical or impractical to build without the use of geotextiles.

COST BENEFIT ANALYSIS EXAMPLE

Introduction

The following cost benefit analysis gives an example of the considerable savings which can be realized by using Exxon GTF fabric.

The savings will be evaluated as follows: a) a calculated savings in required aggregate yielded from the reinforcement characteristics of the geotextile, b) a 40% savings in required aggregate since the geotextile will prevent this loss to the soft subgrade (see figure 4), c) a 100% savings in machinery time will lastly be considered since the geotextile reinforced lift provides a suitable working platform for construction vehicles, i.e., without the geotextile, the equivalent lift would require ten, ten-hour days to be constructed, whereas with the geotextile, the lift would require five, ten-hour days to be constructed.

Input Data

- Width of sample road: 20 feet
- Length of sample road: 1 mile
- Number of vehicle passes: 2000
- Rut depth: 2 inches
- Required aggregate thickness without GTF fabric: 27 inches (yielded from the previous design example p.14)
- Required aggregate thickness with GTF fabric: 18 inches (yielded from the previous design example p. 14).
- Percentage of aggregate expected to be lost to the subgrade if geotextiles are not used: 40% (see figure 4 @ CBR = 1)
- Cost of machinery per hour: $165.00 (one dozer, one compactor, one grader)

- Required time for the construction of the sample road using a geotextile: 50 hours (5 days x 10 hours)
- Cost of aggregate: $10.00/cu. yd. in place
- Cost of Exxon Woven Geotextile: $0.60/sq. yd. in place

Solution

A) Aggregate Costs

	With Geotextile	Without Geotextile
Volume	5867 cu. yd.	12385 cu. yd.
Cost	$58,670.00	$125,850.00
Savings	$65,180.00	

B) Equipment Costs

	With Geotextile	Without Geotextile
Time	50 hours	100 hours
Cost	$8,250.00	$16,500.00
Savings	$8,250.00	

C) Total Savings

Aggregates Savings:	$65,180.00
Equipment Savings:	$ 8,250.00
Sub Total:	$73,430.00
Less the cost of Geotextiles:	$ 7,040.00

NET SAVINGS: $66,390.00

APPENDIX D

DESIGN EXAMPLE USING TENSAR GEOGRIDS

DESIGN EXAMPLE USING TENSAR GEOGRIDS

Given:

A six mile stretch of highway has been designed using a standard cross-section suitable for a subgrade having a minimum CBR value of 5. However, a detailed site investigation revealed a 1-1/2 mile portion of the project has a subgrade CBR value of only 1. Therefore, special subgrade treatment is required over the weak area in order to increase the bearing capacity beneath the pavement to a minimum CBR value of 5.

The conventional approach would be to undercut and remove weak soils and backfill with competent material.

Determine:

Unreinforced and TENSAR Geogrid reinforced fill thickness requirements to improve the pavement subgrade strength to a minimum CBR value of 5.

Materials Available		Installed Cost
Crushed Stone Base	CBR = 80	\$18.00/cy
Select Borrow Clay	CBR = 5	\$8.00/cy
Overexcavation Cost		\$3.00/cy
TENSAR SS1 Geogrids		\$1.60/sy (typical)

Equipment Loads

Dual Wheel Load	P = 11,000 lb
Tire Pressure	p = 100 psi

Solution:

Step 1

Undrained shear strength of subgrade with CBR = 1 corresponds to:

$c_u = 4.0$ psi ... (see Table 4-14)

Step 2

Allowable bearing pressure on subgrade,

Unreinforced

$q_u = 3.1 \times 4.0 = 12.4$ psi

Reinforced with TENSAR SS1 Geogrids

$q_r = 6.2 \times 4.0 = 24.8$ psi

Step 3

Design load, $P = 11{,}000$ lb
Contact pressure, $p = 100$ psi
Contact radius

$$R = [11000/(3.14)(100)]^{0.5} = 5.9 \text{ in.}$$

Step 4

Required thickness of unreinforced fill, z

$$z_u = R/[(1/(1 - q_u/p)^{0.67}) - 1]^{0.5}$$
$$z_u = 19.4 \text{ in}$$

where $q_u = 12.4$ psi (Unreinforced)

Step 5

Required thickness of reinforced fill

$$z_u = 5.9/[(1/(1-24.8/100)^{0.67}) - 1]^{0.5}$$
$$z_r = 12.9 \text{ in}$$

where $q_r = 24.8$ psi (Reinforced with TENSAR SS1 Geogrids)

Step 6

Compare the bearing strength of the fill with the bearing pressure to be applied by construction vehicles.

Bearing strength, q_f (local shear failure controls)

CBR = 5 correlates to:

$c_f = 20$ psi (see Table 4-14)

$= q_f = N_u c_f = 3.1 \times 20$

$q_f = 62 \text{ psi} < p = 100 \text{ psi}$

The fill alone cannot support the dump truck loads. Therefore, either partly loaded trucks or low ground pressure equipment (e.g. dozers) will be required throughout construction to prevent overstressing the fill. On the other hand, a higher bearing capacity fill material may be required if heavy construction traffic must operate over the fill section.

Since the base layer, must have a minimum CBR value of 80, consider the use of a well graded crushed base aggregate (GW) directly on top of the fill. From Figure 4-14, the minimum CBR = 80.

Step 7

Required thickness of base to support construction traffic.

CBR = 5 correlates to $c_f = 20$ (Table 4-14)

$$q_f = N_u c_f = 3.1 \times 20$$
$$q_f = 62 \text{ psi}$$

where N = 3.1 (unreinforced case only)

$$R = 5.9 \text{ (from Step 3)}$$

Required aggregate base thickness

$$z_f = 5.9/[(1/(1-62/100)^{0.67}) - 1]^{0.5}$$
$$z_f = 6.2 \text{ in}$$

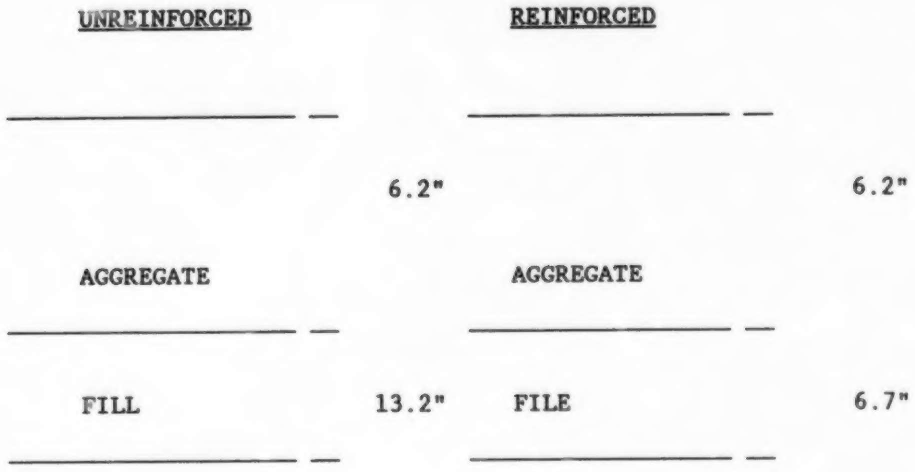
Step 8

Determine the resultant required fill thickness of both the unreinforced and reinforced alternatives.

Unreinforced thickness = 19.4 - 6.2 = 13.2 in.

Reinforced thickness = 12.9 - 6.2 = 6.7 in.

Design Alternatives


UNREINFORCED
REINFORCED
6.2"
6.2"
AGGREGATE
AGGREGATE
FILL
13.2"
FILE
6.7"

Step 9

Determine the maximum allowable construction loads on top of the initial fill layer to prevent failure of the subgrade.

Re-write the Boussinesq stress equation to determine the allowable contact pressure, P_a, at surface.

Maximum allowable stress at depth z = 13.2 in (unreinforced) or z = 6.7 in. (reinforced).

Unreinforced, q_u = 12.4 psi (from Step 1)

$$p_a = q_u/(1 - [1/(1+(R/z)^2)])^{3/2})$$
$$p_a = 12.4/(1-[1/(1 + (5.9/13.2)^2])^{3/2})$$
$$p_a = 51.8 \text{ psi}$$

Reinforced, $q_r = 24.8$ psi (from Step 1)

$$\begin{aligned} p_a &= 24.8/\{1-[1/(1+(5.9/6.7)^2)]^{3/2}\} \\ &= 43.0 \text{ psi} \end{aligned}$$

Use low-pressure vehicles such as bulldozers or partially loaded trucks to spread fill until second layer of aggregate is placed.

Allowable wheel loads, P_a

$$P_a = p_a \times 3.14 \times R^2$$

Assume tire pressure and effective contact radius remain the same but the tire contact pressure is reduced due to the lighter load.

Unreinforced

$$\begin{aligned} P_a &= 51.8 \times 3.14 \times (5.9)^2 \\ &= 5660 \text{ lb/dual wheel} \end{aligned}$$

Reinforced

$$\begin{aligned} P_a &= 43 \times 3.14 \times (5.9)^2 \\ &= 4700 \text{ lb/dual wheel} \end{aligned}$$

Step 10

Economic analysis of reinforced versus unreinforced alternatives.

Fill costs = \$8.00/yd^3
Overexcavation costs = 3.00/yd^3
Total placement costs = \$11.00/yd^3

Thickness savings = 13.2 - 6.7 = 6.5 in.

Volume savings = 6.5 in/36 in/yd
= 0.180 yd
= 0.180 yd^3/yd^2

Fill cost savings = 0.180 x 11.00 = $1.98/$yd^2$

Typical TENSAR SS1 Geogrid costs (in-place) = $1.60/$yd^2$

Net savings = 1.98 - 1.60 = $0.38/$yd^2$